TEXTBOOK OF BRITISH SURGERY

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VOLUME FOUR INFLAMMATION AND PYOGENIC INFECTIONS — BURNS — ACCIDENTAL WOUNDS — INFECTED WOUNDS — ORTHOPÆDICS — DISEASES OF BONE — ARTHROSTEAL TUBERCULOSIS — HÆMATOGENOUS OSTEOMYELITIS AND SEPTIC ARTHRITIS—TUMOURS OF BONE—SURGERY OF THE HIP JOINT—THE KNEE JOINT—SURGERY OF THE HAND—SCOLIOSIS—ANOMALIES OF THE SPINE—PAIN IN THE NECK AND ARM — ANTERIOR POLIOMYELITIS — ORTHOPÆDIC SURGERY IN SPASTIC CONDITIONS — PERIPHERAL NERVE INJURIES — AMPUTATIONS AND ARTIFICIAL LIMBS



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EDITORS' PREFACE

THE advances of Surgery in the last twenty years have been so great that no one individual can master all the fields which they have opened. On the other hand it is important that candidates for the higher examinations should be familiar with the whole subject, for only thus will they be able to select for their future career the branch for which they are best adapted. This new *Textbook of British Surgery* aims to meet their requirements.

It has been compiled by more than fifty authors, each an acknowledged master in his own particular branch, and the aim has been to give a clear and succinct but complete account of the present position in each field. So rapid has progress in surgery been that several of these articles have been completely rewritten while the book was being compiled. At the moment they present an accurate view of surgical practice today on its highest plane. We hope that they will be of material use to the student in acquiring the knowledge which is necessary for his work, and that later on they may inspire him to add to that knowledge and by his own labours to develop still further the great subject to which he is devoting his life.

At the conclusion of the fourth and final volume we should like to take the opportunity of thanking the various contributors whose efforts have made this book possible In a collaborative work of this kind some delays are unfortunately inevitable and the pace of the entire team is largely determined by that of its slowest member This must be our excuse to those who rendered their manuscripts promptly and found that it took rather longer to translate them into print than they had anticipated We should also like to acknowledge our indebtedness of Mr J Johnston Abraham and Mr Owen R. Evans, our publishers, for their wise counsel and helpful co-operation at all times and for the admirable manner in which their firm has produced these volumes.

London, 1959

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J C. G

GENERAL PREFACE

THIS is the fourth and final volume of the *Textbook of British Surgery* It covers the following subjects Inflammation and Pyogenic Infections—Accidental Wounds and their Management—Infected Wounds—Acute Fractures and Dislocations—Mal-Union—Burns—General Orthopædics—General Diseases of Bone—Arthrosteal Tuberculosis—Hæmatogenous Osteomyelitis and Septic Arthritis—Tumours of Bone—Surgery of the Hip Joint—The Knee Joint—Surgery of the Hand—Scoliosis—Anomalies of the Spine—Pain in the Neck and Arm—Anterior Poliomyelitis—Orthopædic Surgery in Spastic Conditions—Peripheral Nerve Injuries—Amputations and Artificial Limbs

Sir Henry Souttar and Professor Goligher as the general editors have in this volume had the assistance of Mr Norman Capener as editor of the section of growing importance associated with orthopædic conditions, and for his help they are most grateful.

All the authors are recognized authorities on their subjects and each has been allowed a free hand to discuss his line of treatment. Any overlapping has been accepted deliberately The authors names are sufficient guarantee that their views are authoritative. They are drawn from leading medical schools and hospitals throughout Great Britain and represent the concensus of opinion in present day British surgery

The volume is essentially clinical and practical with such pathology as is necessary for diagnosis and treatment. Surgical procedures are described and the authors discuss the advantages and disadvantages of each procedure in vogue, indicating their reasons for preferring one to another

The volume is illustrated by original drawings, photographs, X rays, and diagrams. The audiences it is intended to interest are general surgeons, registrars, postgraduate students and those reading for the Fellowship and other higher examinations.

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CHAPTER I

SECTION I

INFLAMMATION AND PYOGENIC INFECTIONS

IAN GORDON

IN dealing with the lesions grouped under this heading it has been the time honoured custom to describe as separate conditions, cellulitis, abscess, boils, and carbuncles. That is a matter of convenience for descriptive purposes but it should be clearly understood that each is in fact but a modification in time place or intensity of the same basic process, namely the reaction of the tissues to invasion by an organism If the surgeon accepts this truth and if he combines it with a sound understanding of the processes of inflammation and repair then the intelligent management of patients suffering from pyogenic infections will be firmly in his grasp

From a study of the salient features of inflammation and repair the surgeon gains an insight into the body's defence against bacteria and can ensure that his treatment will be aimed at helping the defence mechanism and will never impede the formation of or cause damage to the natural barriers set up to resist further invasion. From this study he can evolve certain principles of treatment which are applicable to all bacterial infections, although subject to modification according to the stage of the infection when first seen, the site of infection, the virulence of the invading organism, and the reaction of the host.

INFLAMMATION

This term embraces a series of vascular changes brought about in tissues injured or invaded by an irritant The process is fundamentally the same whether it is initiated by an injury a chemical irritant, or bacteria. Here we are concerned with the response to invasion by bacteria Certain factors modify the response made by the tissues and these will be considered later

How precisely the series of changes in inflammation are brought about is still controversial, though the changes themselves have been recognized for a hundred years Of prime importance is the realization that the changes occurring in inflammation are essential to the defence of the tissues and are not in themselves detrimental.

Immediately the bacteria gain a footing in the tissues the small blood vessels of the part dilate and the rate of blood flow through them increases. Capillaries not previously open are brought into action. The number of leucocytes in the blood flowing through the dilated vessels is increased. The plasma is rich in antibodies produced at distant sites (Fig. 1).

To employ a military metaphor the sole objective of this initial phase is the transportation of the body's troops to the site of invasion The battle is joined when the defending forces disembark from the blood vessels. The second stage of the inflammatory process is concerned with this disembarkation. The flow in the small vessels slows down and may even become stagnant, the lining endothelium becomes swollen

and the blood cells, both leucocytes and red corpuscles, move from their previous position in the centre of the blood stream towards the vessel wall where they adhere to the endothelium. The leucocytes show amœboid movements and migrate into the tissue spaces, fluid plasma escapes through the walls of the capillaries and even some red cells find their way outside the vessel walls. Although towards the centre of the area of infection the blood may be stagnating, the periphery is still in the first phase or stage of

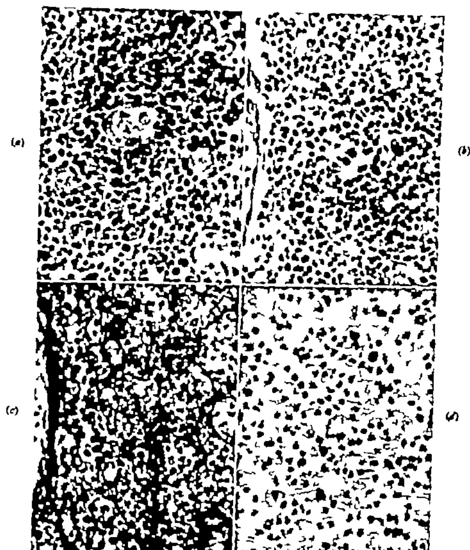


Fig. 1 *Pyogenic Inflammation of the Skin.* the subepidermal zone of a furuncle. Vascularity is increased by opening up of capillaries and the formation of new vessels ( ). The exudate, which is composed of neutrophil granulocytes and plasma cells, ppears to be unsupported and to consist simply of pus (*b*), but silver impregnation reveals a well developed network of young collagen fibres, indicating that the processes of repair are already active (*c*). The earliest obvious evidence of healing is the appearance of phagocytes in the purulent exudate. The darker masses in the macrophages are the nuclei of ingested pus cells, (*d*).

accelerated flow and since many new vessels have opened up the total blood flow through the affected part is much greater than normal. At the site of infection in the tissues the invading organisms are now multiplying rapidly manufacturing their toxins, and causing the death of the cells in their vicinity. The defence forces have now arrived and their objective is to contain, neutralize and destroy the invaders. Fibrin contained in the exuded plasma is precipitated in the tissue spaces and thus assists in sealing off the battle zone. The exudate also contains antibodies and opsonins, the former to neutralize the toxins and the latter to render the bacteria easy of phagocytosis. The leucocytes move in and ingest the organisms (Fig. 1 (c, d))

In the fully developed process three zones can be recognized, though with the waxing and waning of the battle the zones become intermingled. In the central area the microbes are actively dividing, cellular death of the invaded tissue is occurring and the leucocytes are ingesting bacteria or are themselves being destroyed. This is the zone where pus will form and be recognized by the clinical sign of fluctuation.

Immediately surrounding this zone is an area where the flow in the capillaries has become slow or stagnant, or where thrombosis has already occurred. Here the defending forces are disembarking. Clinically in a superficial lesion, this is the area of cyanosis, swelling, and induration.

The peripheral zone is the area of dilated vessels with fast flowing stream—a blood stream in which leucocytes are numerous. In this zone the defending reinforcements are being brought to the scene of battle. Clinically this zone is seen as the red blush which surrounds the pyogenic lesion.

Outcome. Such is the start of all pyogenic infections. What follows depends on many variable factors. Should the defences prove overwhelming, the organisms are quickly ingested and all destroyed. The lymph vascular system absorbs the remaining exudate together with any leucocytes and tissue cells which have been destroyed. Such an issue is known as resolution.

Should the invaders at first prove successful the defence is forced to retreat and the involved area constantly extends. The central zone increases in extent with organisms multiplying and spreading in the tissue spaces. The tissue cells are damaged but not necessarily destroyed. This is the state known clinically as cellulitis. The end of this type of infection is resolution over a wide area but with a small central area of suppuration or abscess formation.

If the defenders succeed in localizing the infection but the organisms prove locally destructive then from an early stage suppuration is the outstanding feature and a well defined abscess cavity will form. Sometimes death of tissue en masse occurs and this result is spoken of as bacterial gangrene. It is most often seen in infections of the fingers, though rarely since the use of antibiotics.

REPAIR

Since bacterial invasion frequently results in tissue loss it is appropriate to consider here the process of repair. Once tissue is destroyed the body immediately endeavours to replace it, first by unspecialized tissue and later by specialized tissue approximating as nearly as possible to the original. While the inflammatory process is active in an area where the bacteria are advancing, in an adjacent area, where pus has formed, the abscess wall will show the changes associated with repair. In this latter area granulation

tissue is forming. The newly formed capillaries extend in loops from the tissues in the wall of the cavity these loops being surrounded by *young fibroblasts. The fibrin deposited* as part of the inflammatory reaction forms the scaffolding for the support and growth of this new granulation tissue. The objective of the granulation tissue is to fill up the cavity resulting from destruction of body cells and the subsequent evacuation of the pus.

As this process advances the older layers of granulation tissue become organized. The fibroblasts become re-orientated *parallel to the surface of the abscess cavity* i.e. at right angles to the outgrowing tufts of capillaries. Collagen fibres are deposited and scar tissue formed This tissue serves two purposes, the filling in and eventual healing of the abscess cavity and as a barrier against spread of the invading organisms.

Regional and Systemic Spread of Infection

In addition to the local changes at the point of invasion just described, spread to distant sites may occur

Spread by Lymphatic Channels. The lymph flow from inflamed tissues is increased. The extent of this increase is dependent in some measure on the muscular activity of the part—*the more active the greater the flow* Bacteria and *their toxins, which are of* relatively high molecular weight are absorbed by the lymph stream rather than by the blood stream. If the part is immobilized, absorption of toxins is minimized. Clinically this absorption of toxins will produce systemic effects but will give no local sign.

Under certain circumstances, however organisms will invade the lymph channels and as they are swept in the lymph stream towards the regional lymphatic gland group they may produce an inflammatory reaction in the walls of the channels and even in the surrounding tissues. Once the glands are reached the organisms produce a similar reaction there. These manifestations are known as lymphangitis and lymphadenitis and are marked clinically by the familiar red streak on the skin overlying the affected channel and by the patient experiencing discomfort in the region of the swollen glands.

Blood Stream. In all pyogenic lesions of any size or severity the blood stream is invaded by toxins which produce the general systemic upset. The severity of the resulting disturbance is dependent especially on the type and virulence of the organism, the anatomical site of the lesion and the resistance of the patient.

Other forms of blood spread are of greater significance. In lesions of marked local severity stagnation of the blood stream in the related capillaries and venules may go on to complete arrest, *with formation of clot. If this clot becomes invaded by organisms,* then spread of the infection can occur in two ways. First the thrombotic processes may spread rapidly along venous channels and thus infection reach a distant site by direct extension. Cavernous sinus thrombosis and infection may be brought about in this way from a primary focus in the upper lip (Fig. 2) Secondly infected clot may become detached and be *swept into the blood stream as an embolus.* This is the condition of pyæmia and it results in metastatic abscesses in sites distant from the original lesion. Metastatic abscesses in the liver following acute appendicitis are brought about as the result of portal pyæmia. Blood culture in pyæmia is usually sterile.

In the related state known as septicæmia, however blood culture is positive and the invading organisms *are found free in the blood stream.* It may be that the organisms are actively growing and dividing in the blood stream, or that their numbers are being

constantly augmented by fresh entrants from the primary lesion The clinical aspects of these conditions will be considered in more detail later

Factors Modifying the Inflammatory Reaction

Of the many factors which may modify the inflammatory process only the more important will be discussed

(1) **The Resistance of the Host** The patient in excellent general health, surrounded by an environment rich in pyogenic organisms and constantly subjected to minor



( ) (*b*)

FIG 2. *Carbuncle of lip.* (*a*) At time of admission Patient had small boil on upper lip. She had squeezed this, rapid extension of infection occurred and cavernous sinus thrombosis resulted from spread along tributaries of the ophthalmic vein. (*b*) Same patient four weeks later Recovery followed treatment with sulphonamides and penicillin.

traumata, must have a strong resistance to invasion by these organisms. Even if the organisms succeed in invading his tissues he is probably capable of repelling the infection

On the other hand, if the host s general condition is poor if he is the subject of a disease such as diabetes or if his defence mechanism is inadequate, for example by lack of antibodies or low polymorphonuclear leucocyte count, then he is at grave risk of being overwhelmed by the invading bacteria.

(2) **The Type of Organism.** Broadly speaking a certain organism will always tend to produce a specific type of lesion The final pattern of the lesion will, however be modified by the general condition of the host, by his degree of immunity to the invading organism and by the virulence of that particular strain. Often the organism involved in a particular infection can be predicted from the situation of the lesion, e.g. coliform bacilli in ischio-rectal abscess, staphylococci in hair follicle infection

(*a*) STAPHYLOCOCCI *Staphylococcus aureus* and *Staphylococcus albus* are the commonest of this group and are found on the skin and in the nose This group of pyogenic organisms is responsible for the majority of soft tissue infections and of cases of osteomyelitis.

Staphylococci all produce one or more exotoxins which stimulate the production of antitoxins The most consistent association between staphylococci and pathogenicity however is the production of coagulase This causes coagulation of plasma which can act as a barrier against the entry of the agents of tissue defence to the site of growth of the staphylococci

The staphylococcus, therefore, usually produces a suppurative lesion. The infection tends to localize early but with tissue necrosis. Softening occurs with the discharge of a central core of necrotic tissue followed by thick creamy pus. The danger of these infections is local tissue damage Examples of staphylococcus infection are boils, carbuncles, and infections of breast and the palmar surface of hand and fingers Many forms of staphylococci are resistant to penicillin

(*b*) STREPTOCOCCI These occur in infected tissues as chains of Gram positive cocci. They are found in the throats of a proportion of normal people.

The most important pathogen of this group is the hæmolytic *Streptococcus pyogenes*. Like the staphylococci organisms of this group produce powerful exotoxins and enzymes. Of the enzymes that causing lysis of fibrin may be chiefly responsible for the spreading type of lesion generally produced.

Streptococcal infections usually result in lesions which spread rapidly and produce a diffuse reaction The local reaction is less intense than in staphylococcal infections. The organisms multiply rapidly and extend along tissue spaces not sealed off by the deposit of fibrin The lesions included under the terms cellulitis, erysipelas, and lymphangitis are most frequently due to streptococcal infections. Many of these lesions resolve without suppuration or with only a very limited area of necrosis and softening. The discharge from such a lesion is thinner and more sanguineous than the discharge from a staphylococcus lesion. As a rule the danger of streptococcus infections lies in the general systemic upset produced. Fortunately as yet there are no forms of *Str pyogenes* resistant to penicillin.

(*c*) COLIFORM BACILLI Among the less common pyogenic organisms are the coliform bacilli which are associated with infection outside the alimentary tract of which they are normal inhabitants. They are commonly found, for example in appendicitis, peritonitis, cholecystitis, and ischio-rectal abscess. Not infrequently also they are found in nail fold infections in nail biters. The urinary tract is another system commonly invaded by the coliform bacilli The lesions are usually of suppurative type.

(*d*) PSEUDOMONAS PYOCYANEA. This is a pigment producing Gram negative bacillus like the coliforms. It often gives rise to a persistent form of infection in a wound. It seldom occurs alone and is most often superimposed on an existing infection. Due to the production of a pigment the pus has a distinctive greenish blue colour *Pseudomonas pyocyanea* is not sensitive to penicillin and thus as a causal agent of infection it has been on the increase in recent years. It commonly occurs in burns, urinary infections, and chronic suppuration in the middle ear

(3) **The Time Factor** Time has to be considered not only as judged by the clock but in the sense of the stage reached by a pathological process—what might be called

"pathological time." For example, at one time the view was widely held that in with appendicitis, seen for the first time 48 hours after onset, conservative or treatment should be applied because by that time the inflammatory process walled off and any surgical interference would only serve to spread infection case, however the infective process might be walled off in 24 hours, in another 3 days While in general terms the stage of inflammation is dependent upon which has elapsed since the onset of infection, there may be wide variation in required to reach a particular stage

All active infections are at first in a stage similar to what is called clinically Immediately after onset all the modifying factors come into play and in one lesion may spread rapidly localize, and resolve all in a matter of days, whereas patient a lesion caused by the same organism, in the same site may continue before the infection is overcome.

We think of the common pyogenic organisms as producing acute infl conditions and of an organism such as the tubercle bacillus producing a cl flammatory lesion, but the terms acute and chronic simply imply rapid and slo one set of circumstances the pyogenic organisms can produce a slowly progr slowly healing lesion, as in chronic osteomyelitis and varicose ulcer On the ot the tubercle bacillus, although usually producing a chronic lesion, may on produce a rapidly spreading one, e g. tuberculous meningitis

Broadly speaking, with the passage of time an inflammatory lesion become irrespective of the causative organism. Tissue destruction and liquefactio Granulation tissue forms only to be infected and replaced by a more organiz fibrous tissue. Thus the lesion becomes more indurated and its walls more rig pus forms and discharges on the surface, the tract leading from the lesion to t has rigid walls lined with infected granulation tissue.

In several respects the exudate in chronic inflammation differs from that in type. Many of the inflammatory cells are of the mononuclear series, lymphocyt cytes, and plasma cells. These cells multiply locally and also reach the tissues by from the vessels. Macrophages and foreign body giant cells are frequently chronic inflammatory lesions, especially where degenerative changes have ta

(4) **The Site of Infection.** Whatever the site of an inflammatory lesion important factor in deciding its fate is the power of the natural defence mec contain the infection by setting up an inflammatory barrier around it to de ingest the organisms and to repair and replace the damaged tissue. At the the course and ultimate fate of an infection may be influenced by certain a and physiological features of the particular site. An area, clean and with a supply though subjected to frequent minor traumata, will seldom be the extensive inflammatory lesion. Such an area is the tongue.

In contrast, avascular fatty tissue near the anus subject to the repeated t pressure, readily falls a victim to infection. Such conditions exist in the ischio-rec

Areas of skin rich in hair follicles, and in sweat and sebaceous glands, are the site of pyogenic infection by organisms which normally inhabit the area. T outlet from such cavities becomes blocked and in the retained secretions the find an opportunity to multiply and invade the tissues

Once infection is established in a particular site the line of direct sprea

determined by the anatomical features of the part. As the invaders press home their early advantage they tend to spread along the natural tissue spaces, e.g. where there is areolar tissue and they tend to be turned aside by coming up against a rigid structure such as an aponeurosis

Here it must be stressed, however that the inflammatory barrier as it is forced *outwards by the advancing organisms, affects all tissues, so that the exudate seals off* potential spaces, causes the adhesion of tissues which previously have moved freely in relation to one another and in addition vascularizes, thickens, and softens even rigid structures such as an aponeurosis. Thus, though the pus resulting from the infection may track more readily to the nearest free surface, or spread more rapidly along the surface of an aponeurosis, yet, if given time it may penetrate even an aponeurosis. For example, pus contained under the periosteum in osteomyelitis may erupt through the periosteum and an abscess in the tracheo-bronchial glands may rupture into the trachea.

Lastly it is noteworthy that certain structures are more liable to infection when physiologically active. Examples of this are the lactating breast and the growing end of a long bone.

(5) *Trauma. The site of infection is frequently determined by a single trauma*—an abrasion of the surface, a cut or penetrating injury or a blow which causes a hæmatoma in the deeper structures *without breaking the skin*

Trauma, however may modify an existing infection A patient who develops a boil in the eyelids or lip imagines he can shorten the duration of the infection by squeezing the boil when pus has not formed, or if pus is present it is still some distance from the surface. The effect of this trauma is disastrous. The newly formed inflammatory barrier is damaged and there is a rapid spread and intensification of the infection (*see* Fig. 2)

If, however the trauma is minimal but often repeated, then the effect is less dramatic but none-the-less definite. As the repeated trauma injures the defence mechanism and leads to further spread and continuation of the infection, so more tissue is damaged, *more fibrous tissue is laid* down and chronicity results.

These effects are well known to every surgeon but few pay heed to the lessons to be learnt from them.

(6) Hormonal. Drugs such as cortisone and its analogues are now in daily use. Cortisone modifies the tissue reaction to irritants and to tissue loss to such an e· that this side effect must be borne in mind when the question arises of administering tl drug to a patient who has an acute pyogenic infection or a recently repaired wound.

Clinical Effects of Bacterial Inflammation

Local Effects. *The local heat, redness, and swelling are readily related to the vas*·· and exudative phenomena of inflammation. Pain is a prominent symptom but is so readily related to the pathology of pyogenic infection. As pain is intensified by movement or injury to the inflamed tissues, it plays an outstanding part in the by compelling rest. The pain arising from an infected area is generally ··ed to the area involved, it is constant and throbbing in character and is aggravated movement or injury It is important to emphasize that pain continues only so long as infection is active and spreading and once the defence succeeds in localizing the activi of the bacteria the pain subsides. It has been argued that increased tension plays part *in the production of pain—the classical example being infection of the pulp of*

finger It is often preached and practiced that incision of the inflamed pulp will relieve pain but if the pulp is incised in the early stages while the infection is still spreading and before localization with pus formation has occurred then either no relief is obtained or relief is fleeting.

Tenderness is diffuse in the early phases of the infection but in late well localized conditions it is usually confined to the area of fluctuation Extension of the area of tenderness even beyond the confines of the erythematous area is evidence of spread while shrinkage of this area is an indication of localization

Constitutional Effects In addition to the local effects there are certain constitutional changes which occur simultaneously with the local reaction to invading bacteria These changes fall into two groups firstly those subserving the primary function of defence and secondly those which are due to poisons absorbed from the local lesion

PYREXIA Pyrexia is usual in inflammatory conditions and may even be part of the defence mechanism The high temperature is due to increased metabolism in the tissues and to reduction in loss of heat by the skin The loss of heat by the skin is under the control of a heat regulation centre and in fevered states this thermostatic control is set for a higher level than normal

LEUCOCYTOSIS. The rise in the number of polymorphonuclear leucocytes circulating in the blood in most pyogenic infections is necessary to provide the large number required at the site of bacterial invasion This leucocytosis must be brought about by stimulation of the bone marrow but whether by the circulating bacterial toxins or by some other substance produced by the damaged body cells is not known

PRODUCTION OF ANTIBODIES The question of antigens and antibodies cannot be fully discussed here but a word about the production of antibodies is necessary In microbic infection the bacteria and their toxins act as antigens and stimulate the production of antibodies. The antigens are prepared or modified by the cells of the reticulo endothelial system while the actual production and transportation of the antibodies is the function of the plasma cells and lymphocytes The lymph glands regional to infection are specially active in the production of antibodies In response to infection antibodies are soon to be found in the blood lymph fluid and inflammatory exudate

Antibodies can act in the body by neutralizing toxins, by opsonic effect and by bacteriolysis. Precipitation and agglutination which are produced by antibodies reacting with antigens in test tubes, are of doubtful significance in the body

TOXAEMIA. As generally employed this term denotes a group of non-specific symptoms and signs which we associate with any infection and which is produced chiefly by the bacterial endo-toxins. Pyrexia, increased pulse rate headache pains in the limbs nausea vomiting, and delirium may all occur

If this condition persists for any length of time or if it is severe from the onset, the bacterial toxins may damage the parenchymatous cells of the liver kidneys, heart and other viscera producing "cloudy swelling" or "fatty degeneration. Amyloidosis is a less common result of long-standing bacterial infection.

Principles of Treatment

The principles that should guide the surgeon in the management of patients suffering from pyogenic infections are the promotion of the natural defence mechanism in all its phases and the avoidance of any treatment which harms it

General Treatment. The vast majority of pyogenic infections can now be treated on an ambulatory basis. Few require any very strict regime It is obvious that if the patient is debilitated, is suffering from a definite systemic disease such as diabetes or anæmia, or has marked systemic effects arising from his infection, suitable counter measures must be adopted.

Chemotherapy is now an essential part of the treatment of many pyogenic infections In view of the increasing number of strains of organisms resistant to the antibiotics, especially penicillin, the indications for the use of antibiotics should be given careful consideration. There has been a tendency in the immediate past to administer penicillin in even the simplest of pyogenic infections, infections which in the past were adequately cared for by the unaided natural defence mechanism. None the less when the infection is giving rise to considerable systemic upset, is locally severe, or by reason of its position is threatening function, the antibiotics should not be withheld. Until the invading organism, its type, and antibiotic sensitivities can be determined by culture of the discharge from the presenting lesion, treatment should be instituted by the administration of penicillin. On the other hand, if by reason of the site of the infection or the nature of the discharge, the presence of an organism other than one known to be sensitive to penicillin is suspected, the appropriate antibiotic should be administered.

Most pyogenic infections give rise to considerable pain and sedation is, therefore, an essential item in treatment.

Local Treatment. The first phase of defence is aimed at increasing the blood supply to the area invaded by organisms. All local treatment should at first be directed towards promoting this increased vascularity The application of heat and splinting of the part can best achieve this. The value of a poultice of the kaolin type is that it provides both heat and rest to the part.

Because tourniquets and local anæsthetics diminish the blood supply to an infected area their use should be limited.

The initial phase of increased vascularity is followed by the phase in which the infection is localized by the building up of an inflammatory barrier In this phase, rest is of paramount importance. To avoid movement and trauma the part should be splinted and in the upper limb a sling is invaluable. It is in this early phase that all attempts to express small beads of pus from the centre of an indurated inflammatory lesion should be scrupulously avoided.

Surgical Measures. The scalpel has no place in the treatment of early non-localized, pyogenic infections. By early incision of an inflammatory area where no stable localization has occurred, the surgeon will only damage the natural defensive barrier allow invading organisms a quick entry to tissues not yet mobilized for defence, and by the production of a wound make new demands on an already over strained blood supply

The only regular exception to this rule is where the infection is situated in an organ which can be readily dispensed with in its entirety—viz. the appendix. Tiny lesions in other parts could theoretically be treated by excision, but if left alone nature will cope with these with much less loss of tissue and with far less disturbance to both patient and surgeon. At one time excision of such a lesion as a carbuncle was advocated, but this resulted in very considerable loss of tissue and later gross scarring and contracture

Once the natural defences, aided by chemotherapy heat, and rest, have succeeded in localizing the infection and when there is definite clinical evidence of pus formation,

id only then should the knife be used to permit egress of the products of suppura Thus the knife is only used to hasten the process of evacuation of pus from a well abscess which nature would finally achieve by pointing and spontaneous rupture ssings. Organisms require moisture and they thrive in sodden tissues. For this it is unwise to steep the infected part in baths of antiseptic solutions for pro- periods or to enclose the dressing in waterproof material It is valuable to wash t at the time of each dressing with a weak solution of cetavalon or soap

e most valuable type of dressing is one composed of gauze moistened with an tic lotion. Where there is adherent slough its separation will be aided by eusol gs Hay s wash or saline are useful in the later stages when the wound is clean anulating. In this period vaseline impregnated gauze dressings are satisfactory s of first importance that the dressing should be of adequate size and firmly applied. ng is more rest destroying than loose dressings too frequently changed.

inal word of warning is necessary any form of dressing is capable of causing a sensi n reaction, first in the skin around the wound and later spreading to the skin at distant When seeking the cause of any such reaction the textile used should not be forgotten.

summarize, the principles of treatment are

) General measures, including chemotherapy

) Local application of rest and heat.

) Incision only when complete localization has occurred

Clinical Lesions

describing certain clinical types of lesions produced by infection it must be stressed that are descriptive terms and merely denote modifications of the same fundamental process.

ellulitis. This term is applied to an acute spreading inflammatory process resulting invasion of the tissue by pyogenic organisms. It is a term which from the patho- l aspect could be applied to the early changes resulting from invasion of organisms y tissue, and should be applied so long as no successful localization of the infection ccurred. Thus it could rightly be applied to such various conditions as pneumonia, e peritonitis, meningitis, and tenosynovitis. Clinically however the term is used iptively to indicate a diffuse, rapidly spreading infection by pyogenic organisms, ly the streptococcus, and involving most commonly the subcutaneous tissues

ntry of the organism is gained through some slight, often unidentifiable lesion, such pin prick or a small abrasion.

he combination of such factors as a virulent organism and a debilitated patient produce a very widespread lesion, an intense constitutional disturbance and even a issue.

LINICAL FEATURES. The onset of constitutional disturbance is sudden and may precede any awareness of a local lesion by the patient The illness may be ushered a rigor with a temperature as high as 103 F Often this is accompanied by anorexia ea, and even vomiting. Not infrequently the patient is next aware of pain tender and swelling related to the lymphatic glands draining the area involved in the loping cellulitis. If the patient is reacting normally to the bacterial invasion, cytosis will occur Glycosuria is sometimes present and may be transient or may ate that the patient is a diabetic subject.

The early local manifestations are pain and tenderness in the affected area—most

commonly the front of the leg, the forearm, the face or scalp This area rapidly increases and the overlying skin becomes hot and reddened. There is marked swelling of the affected part and in the lower limb especially there may be gross swelling distal to the lesion. As the invasion advances all these local features become intensified, the regional lymphatics show as red lines running from the lesion to the already swollen and tender regional lymphatic glands and the constitutional disturbance becomes aggravated.

OUTCOME. Under modern conditions a cellulitic area in a patient of normal resistance should resolve completely The area involved will gradually contract, the lymphadenitis subside and the constitutional disturbance vanish as rapidly as it developed. If suppuration does occur it is usually very limited and a small localized abscess forms. Infrequently suppuration with abscess formation occurs in the regional lymph glands.

In sharp contrast to the foregoing there is the occasional patient, often debilitated, in whom extensive necrosis of skin and subcutaneous tissues takes place. With the increasing understanding of the bacteriology of these infections and the proper use of the available antibiotics, such severe lesions are seldom encountered.

TREATMENT Ideally the patient should be treated at rest in bed, and this is especially desirable when the lesion is in the lower limb Diet should be light with adequate fluid intake. Proper sedation should be ensured and all nursing measures to increase the patient s comfort adopted. This is the type of lesion in which chemotherapy shows its most dramatic results, and it should be instituted immediately The hemolytic streptococcus is always sensitive to penicillin and the sole issue is to ensure correct dosage and administration. In the absence of any exact knowledge of the organism and its antibiotic sensitivities in the individual case, penicillin is the antibiotic to use in the first instance. It should be given parenterally The dosage should be ½ to 1 million units, given twice daily or 4-hourly if desired. If the organism is sensitive to penicillin and the other measures advised are carried out, the response to treatment should be apparent within 48–72 hours. If there is no response the antibiotic should be changed. When suppuration has occurred material for culture can be obtained and definite knowledge of the invading organism and its sensitivities procured.

Local measures should include rest for the limb or affected part, heat in the form of kaolin applied and surgical intervention considered only if and when suppuration with abscess formation occurs. Early incision before suppuration has occurred amounts to mismanagement or worse.

COMPLICATIONS. These should not occur unless the patient s resistance is low the invading organism virulent and insensitive to the antibiotics or the treatment neglected.

(*a*) *Bacteræmia and Septicæmia* In this state organisms can be grown by blood culture The patient s constitutional disturbance is intensified with rigors, delirium and hectic fever his condition may deteriorate and end in coma and death.

Treatment consists of the more strenuous application of the measures already in use and in adopting such additional measures as fresh blood transfusion and the use of any antisera that may be appropriate. As a rule a few days will decide the issue between death and survival with complete recovery

(*b*) *Abscess Formation.* This may occur either in the local cellulitic area or in related lymph glands. Very rarely it occurs along the line of the inflamed lymphatic channels. Spontaneous rupture will probably occur or surgical incision can be carried out to give adequate drainage.

(c) *Pyæmia* This condition is a complication more likely to appear when suppuration has occurred. Infected blood clot or other necrotic material harbouring active organisms escapes into the blood stream This septic embolus is responsible for starting a new lesion in another part of the body

With the development of each successive new lesion the patient has a relapse of his constitutional disturbance and complains of local symptoms according to the site of the most recent infection This illness tends to become protracted and treatment consists in dealing with each new abscess as it arises, together with the appropriate general measures. Unfortunately not infrequently death is caused by the mischance of an abscess arising in the lung, the brain, the liver or the kidney

(d) *Hæmorrhage* When suppuration intervenes and the tissue affected is in the neighbourhood of a large vessel, severe hæmorrhage can sometimes occur This may happen when the patient s condition, both general and local, is apparently progressing satisfactorily

Erysipelas. This is an acute, rapidly spreading, non-suppurative inflammation of the skin. Erysipelas affects especially the skin of the face and often commences around the nose or mouth. It is seen less commonly in the scrotum and the limbs Severe attacks are usually met with in infants or the aged Debilitated persons are also liable to gross constitutional upset during an attack.

Erysipelas is due to infection with any hæmolytic streptococcus and the organism gains entrance through a small prick or abrasion. Microscopically the infection can be seen to be mainly in the lymphatic plexus of the dermis and the lymphatic channels teem with streptococci The area of skin affected is raised, reddened, tense, and shiny Small vesicles sometimes appear near the margin, which is irregular in outline and visibly and palpably raised above the level of the normal skin. The whole area is exquisitely tender

Treatment Erysipelas is usually a self limiting disease and subsides spontaneously within a week, but it is apt to recur Local heat will afford comfort to the patient and the use of penicillin by the parenteral route will abort the attack. In the special groups already mentioned the disease may be serious and the outcome fatal.

Erysipeloid of Rosenbach. This infection usually seen on the hands of those handling meat, fish, or poultry is discussed in the section dealing with infections of the hand

Boils. This name is given to a localized suppurative condition occurring in the skin, most commonly in the hair bearing areas. It is generally due to infection by *Staphylococcus aureus* arising in a hair follicle or blocked skin gland. The lesion commences as a painful, red, swollen, and tender spot which gradually extends in area and in induration. Later suppuration takes place with the separation of a necrotic centre. When this core is extruded there is escape of pus and thereafter healing is usually rapid Constitutional disturbance is minimal. The regional lymphatics and glands may be inflamed but less commonly than in cellulitis.

Treatment The condition is best treated expectantly with rest to the part, the local application of heat and the use of antibiotics if the constitutional disturbance warrants it. When localization and suppuration have occurred the resultant purulent blister can be snipped with scissors as part of the dressing technique. Occasionally a more formal incision will be necessary There follows a period of daily moist dressings with eusol or some similar antiseptic lotion, before final healing. Thorough cleansing of the skin is the most valuable preventative measure

Recurrent Boils. Many patients suffer from recurrent boils which may present in two clinical forms

(*a*) In the first group the patient over a period of weeks or months has isolated boils occurring in different sites, such as the back of the neck, trunk, forearm, thigh, and buttock. Each boil must be treated as it occurs and any possible cause for lowered resistance to infection sought and dealt with. Some success may be achieved by the use of a *vaccine prepared by culturing the organism found in the discharge from an individual lesion*

(*b*) Patients of the second group suffer from recurrent attacks of crops of small lesions arising always in the same area. The cause is to be sought in the presence of some local irritant. For example, this type is seen in the *forearms of patients working with* material such as engine oil, which blocks the openings of skin glands and hair follicles. It is seen in patients with acne affecting the back of the neck and upper trunk. One very persistent and troublesome form is that occurring in the hair follicles and skin glands of the axilla.

In treatment, attempt should be made to prevent the infection of adjacent hair follicles by pus exuding from an active lesion. An antibiotic cream smeared thinly over the surrounding skin is a useful aid In prevention the patient should be withdrawn from contact with the causative irritant or if this is not readily possible, then the irritant should be removed at frequent intervals by thorough washing of the affected area.

Carbuncle. This lesion tends to occur on the back of the neck, on the trunk, or occasionally in the upper lip of males in the middle aged or elderly group It may occur in a debilitated patient and is often associated with glycosuria.

A carbuncle is essentially similar in its pathology to a boil In effect, it is a group of boils that have become coalescent. Thrombosis of vessels occurs, with death of tissue.

In a patient with a carbuncle in the developed state the constitutional disturbance is severe. There is anorexia, nausea, and vomiting, together with a dry furred tongue and *intense thirst*. The pulse rate is increased and the temperature swinging. Bowels are constipated. Glycosuria may be present.

The carbuncle presents in the form of a large indurated swelling. The skin overlying the periphery of the swelling is red and brawny while that covering the central part is cyanotic and may be sloughing. Usually there are several points of discharge in the central area, from which thick pus is exuding. The central area becomes fluctuant due to the collection of pus and slough. Regional lymph glands are very swollen and tender

Treatment (*a*) General. The detailed treatment has been given already when discussing the condition of cellulitis and it need not be repeated It should be stressed that any underlying debilitating disease must be searched for and treated. Glycosuria, if present, should be investigated and assessed. Not infrequently it is transitory will co-exist with a normal blood sugar curve and is presumably toxic. On the other hand, the carbuncle is often the presenting sign of diabetes mellitus.

The antibiotics should be used in full measure Before suppuration and discharge occurs, penicillin is the first choice. When material is available for culture the organism should be identified and its sensitivities ascertained.

(*b*) Local. Rest, heat, and moist eusol dressings form the basis of local treatment. Surgical measures should be confined to incision of collections of pus and to the removal of slough. Excision is not to be recommended.

PROGNOSIS. Under modern management a carbuncle should heal well without great loss of tissue and, therefore without the gross scarring, resultant contracture, and deformity so common in the past.

Carbuncles of the upper lip have an evil reputation Spread of infection in the form of infective thrombophlebitis involving the veins of the face can take place. Venous drainage into the ophthalmic vein and thence into the cavernous sinus could carry infection inside the skull, with all the serious contingencies that this implies (Fig. 2) With antibiotic treatment this is very unlikely except in the neglected case or in the patient already extremely debilitated.

The patient with a boil on the upper lip should be warned not to attempt evacuation of the pus by squeezing. In this area such a practice is most dangerous and will cause spread of the infection

In the past pyæmia, with resultant infection at some distant site, was a common and serious complication of carbuncle

Abscess. This is not an entity It is simply the descriptive term for the collection of pus which results from suppuration in an inflammatory area. The pus and necrotic tissue lies in a cavity whose wall is well defined. The wall consists of tissue which in part shows the reaction of inflammation but more generally consists of granulation tissue actively attempting to close the cavity

By the time a well localized abscess has formed, the constitutional disturbance is usually subsiding. Locally an abscess presents as a painful tender swelling with the overlying skin reddened or perhaps cyanotic and even sloughing. Fluctuation is well marked, indicating the underlying collection of pus.

TREATMENT The treatment is essentially surgical Once the collection of pus is well delineated the surgeon can offer nature the maximum aid and by a well placed and adequate incision help to dispose of the accumulated debris.

It might not be inappropriate here to suggest that if the abscess is in an area of loose skin such as the axilla, it is wise to excise an elipse of that integument. If a linear incision is made the edges may come together before adequate drainage and complete filling in of the abscess cavity by granulation tissue has occurred.

A word about certain adjuvant methods of treatment is necessary

Hilton's method of opening an abscess has stood the test of time and is specially applicable to deep abscesses in the neck, where an incision down to and through the wall of the abscess might endanger important structures. A superficial incision is made sinus forceps inserted and driven inwards till the abscess cavity is reached. The opening thus made can then be gently enlarged by separating the handles of the forceps.

Drains, which may be strips of corrugated rubber or rubber tubes, are useful to maintain drainage of abscesses with thickened rigid walls, and such pathways can be used to wash out the cavities with antiseptic lotions or solutions of antibiotics.

Packing can be used as an alternative to rubber drains and is specially valuable where there is a large cavity with hæmorrhagic oozing. The packing can be immersed in an antiseptic or antibiotic lotion prior to insertion in the wound. Packing, if inserted too tightly may defeat its purpose by preventing drainage

Lymphangitis. This term denotes a condition in which lymphatic channels invaded by bacteria show up on the skin as red tender streaks. Lymphangitis is best seen in the lymphatics of the forearm and in those accompanying the internal saphenous vein. The

primary lesion is often quite insignificant, e g. slight infection at the edge of a finger nail fold, and the organism is most commonly the streptococcus, though sometimes a mixed streptococcus and staphylococcus infection occurs. The related lymphatic glands become painful, swollen, and tender and suppuration may occur though not commonly If an abscess does form and is incised, not only is pus evacuated but usually several necrotic glands are found in the wall of the abscess.

Much more rarely suppuration occurs along the line of the inflamed lymphatics between the primary lesion and the regional glands

TREATMENT This is directed to the primary condition. Most organisms causing lymphangitis are sensitive to penicillin.

As resolution occurs the redness dies away and for a time thereafter the lymphatics can be felt as hard, slightly contracted cords.

Lymphadenitis. During any pyogenic infection the regional lymphatic glands may become involved Lymphangitis may accompany lymphadenitis but the latter is much more common. The glands may become swollen during the acute phase of the infection, in which case the lymphadenitis frequently settles without suppuration. Not infrequently weeks after the primary infection has settled the glands for the first time become swollen and tender and in this case often proceed to suppuration and abscess formation.

TREATMENT Treatment is by rest with the local application of heat. If breakdown with abscess formation occurs then incision is advisable. Where lymphangitis is present, and before suppuration occurs, the antibiotics should be exhibited.

Sinus. When sepsis is persistent in the deeper tissues a tract may lead to the skin surface where the opening is small, circumscribed, and pouting. This tract is called a sinus. It is lined with granulation tissue and is surrounded by fibrous tissue. Usually the cause lies in some retained foreign body or in tuberculous adenitis, is due to the presence of calcification in necrotic glands.

TREATMENT Treatment consists in opening up the tract and removing the cause of the continuing infection

Fistula. This term denotes an abnormal channel passing from the skin or a serous surface to a mucous surface, or from one mucous surface to another An example is the common anal fistula, where the external opening is on skin overlying one or other ischio-rectal fossa, and the internal opening is on the surface of the lining of the anal canal or rectum. Other examples are a broncho-pleural fistula and the vesico-colic fistula sometimes associated with diverticulitis of the pelvic colon.

TREATMENT This varies according to the site and cause of the fistula.

Infection of Surgical Wounds

Theoretically infection can reach a clean surgical wound from three main sources.

(a) The patient s tissues.

(b) The instruments and dressings used by the surgeon and his theatre team and the hands or naso-pharynx of these operators.

(c) The atmosphere.

These cannot be considered in detail here, but certain factors which increase liability to infection are worthy of study

Blood clot and damaged tissue forms an excellent medium for the growth of organisms. Every effort should be made to avoid bruising of the wound edges, to secure adequate

hæmostasis and to avoid contamination from any source of infection Drainage tubes, by irritating the wound edges, may set up conditions favouring infection Drainage through separate "stab" wounds is usually preferable to drainage through the main wound.

The infecting organisms if derived from the skin of the patient, the operator and his instruments, or the atmosphere are usually staphylococci or streptococci If infection is from the alimentary tract the coliform bacilli and intestinal anærobes are the most common organisms.

Once infection has arisen it causes œdema and redness of the wound edges, the surrounding tissues are indurated and slight purulent discharge commences at the stitches.

TREATMENT This is expectant and consists of heat, rest, and appropriate chemotherapy Once pus has formed the removal of one or more stitches will often allow it to escape If the infection is arising from a deeper source e g. in the peritoneal cavity a formal opening of the wound and establishment of adequate drainage is required.

Wound Infection due to Anærobic Streptococcus. The anærobic streptococcus in association with the common pyogenic streptococci and staphylococci, is now known to produce several types of specific infection Meleney (1933) drew attention to these lesions. Three of these conditions will be described.

(*a*) CHRONIC UNDERMINING ULCER This was first described as affecting the abdominal wall or the groin but it is also seen in the lower limbs. It is an uncommon lesion. Infection starts in an operation wound or at the site of a known injury Sometimes there is no obvious portal of entry A localized ulcer with sloughing base, results, the edges become undermined and infection burrows outwards in the subcutaneous tissues. The infection then erupts on to the surface at some distance from the original ulcer leaving intact bridges of skin in between

Other lesions may start at sites distant to the primary one and burrow outwards in similar fashion. The affected area is extremely painful and tenderness is acute over a wide area

Treatment Treatment is both general and local Culture of the discharge under ærobic and anærobic conditions will reveal the nature of the infecting organisms and appropriate tests their sensitivity to available antibiotics The chosen antibiotic, which will usually be a tetracycline, can be administered parenterally and solutions used to wash out the local lesions. Local treatment is aimed at excising the overhanging edges of the ulcer and exposing the infected tissues to the action of oxidizing agents such as the air and solutions of zinc peroxide or hydrogen peroxide

(*b*) PROGRESSIVE POST-OPERATIVE GANGRENE OF THE SKIN. This arises in the skin around the drainage wound of a lesion such as empyema or appendix abscess It can occur in relation to a colostomy wound. Fortunately the condition is rare and is not so intractable to treatment as formerly The organisms respond to chemotherapy applied generally and locally and the extensive surgical excisions practised at one time are no longer necessary or desirable

The condition can be recognized in its early stages by the purple area of skin immediately around the wound edges, surrounded by an outer area of bright red skin. The tissues are painful and tender over a wide area. If untreated, necrosis of tissue spreads remorselessly and an every widening area of ulceration appears The ulcerated area has undermined gangrenous edges surrounded by an indurated erythematous zone

(*c*) ANÆROBIC STREPTOCOCCAL MYOSITIS. In the Second World War an unusual infection of the subcutaneous and muscle tissues was recognized Anærobic streptococci, associated with other pyogenic organisms were shown to be the cause The condition closely resembles gas gangrene but can be differentiated by the slower onset, less marked systemic upset and certain local features of which the chief is retention of contractile power by the affected muscles. Establishment of the diagnosis by bacteriology is important, because less drastic local measures can be adopted than when infection is due to clostridia.

SECTION II

PYOGENIC INFECTIONS OF THE HAND

In an industrial country the proper treatment of injuries and infections of the hand is of prime importance, not only to the individuals concerned but to the community as a whole. Infection is the main cause of permanent deformity and disablement It may arise without obvious trauma, as a sequel to a minor trauma or as a complication of major injury In this section it is not proposed to discuss infection following major injury

Bacteriology

The vast majority of infections in the hand are due to strains of the *Staphylococcus aureus* Certain lesions on the dorsum of the finger near the nail fold, and subepithelial spreading infections, are frequently due to invasion by streptococci. In nail biters localized suppurative infection in the nail fold is not infrequently caused by coliform bacilli Despite an increasing frequency of resistant strains of staphylococci in hospitals, the majority of staphylococci and all hæmolytic streptococci found as the causative organisms in hand infections are penicillin-sensitive.

Anatomy and Pathology

A. B Kanavel (1926) of Chicago made exhaustive studies of the anatomy of the hand with the special objective of demonstrating the likely line of spread of infection arising in any particular site. He examined serial sections of the fingers, hand, and forearm to determine the situation, extent and communications of potential tissue spaces, and also carried out experiments in the cadaver with the injection of radio-opaque solutions into these tissue spaces and into the synovial sheaths to outline their extent and show the *usual points of rupture On the basis of this work* Kanavel stressed the importance of the mid palmar and thenar spaces in the palm of the hand and the subaponeurotic space on the dorsal aspect. He felt that infection in the hand tended to be compartmented in this anatomical way and devised special approaches for surgical drainage (Figs. 3 and 4)

In flexor tendon sheath infections Kanavel taught that once the sheath was infected it became filled with purulent fluid which would act very like the radio-opaque solution injected under tension. With tension rising in the sheath, rupture would take place most probably at the proximal end, thus infecting the palmar spaces. In infections of the tendon sheaths of the thumb or fifth fingers, rupture might take place in the forearm with resultant infection of the space (Parona) deep to the tendons. In addition it was

argued that tension within the sheath would interfere with the blood supply of the tendon and cause it to slough For these reasons Kanavel advised against delay in opening the tendon sheath once a firm diagnosis had been made. The incisions for drainage were laterally placed and if necessary on both sides of the involved finger (Fig. 4)

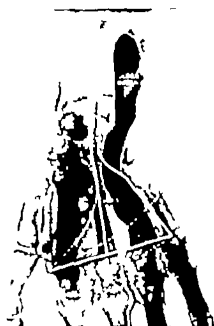


FIG. 3 X-ray of hand after injection of radio opaque material showing position of ulnar bursa, the thenar and middle palmar spaces
A. Deep palmar arch
B Thenar space
M.P.S Middle palmar space
○ Kanavel recommends this site for opening middle palmar space
(*Reproduced from Kanavel, Infections of the Hand, Lea & Febiger*)

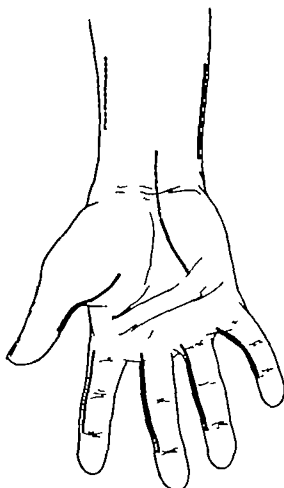


FIG. 4 Illustrates site of incision recommended by Kanavel for opening infected tendon sheath.
(*Reproduced from Kanavel, Infections of the Hand, Lea & Febiger*)

From anatomical studies of the pulp of the fingers it was deduced that rising tension due to the inflammatory reaction would compress the small vessels traversing the pulp to reach the shaft of the distal phalanx. Early incision was, therefore advocated to avoid sequestration of the distal two-thirds of the phalanx.

This very brief account of the clinical and laboratory researches of Kanavel serves to point three main trends in his teachings

(1) That anatomical barriers played a very large part in determining the limitations and lines of spread of pyogenic infections in the hand.

(2) That early incision is advisable to prevent spread of infection by eruption from one anatomical compartment to another and to prevent loss of tissue by avascularity due to rising tension.

(3) That incisions in the finger should be laterally placed, for palmar scars were thought, at the worse, to allow herniation of the tendons, and at best, to become tender contracted, and adherent.

This teaching has been widely accepted and has formed the basis of surgical treatment of hand infections for many years. More recently however doubts have been expressed as to its soundness at the present time when, with the aid of antibiotics, it is possible to *modify drastically the course of sepsis in this situation as elsewhere in the body* It has to be remembered too that in Kanavel's injection experiments in cadaver hands, the radio-opaque fluid was injected very rapidly and under considerable pressure so that tissue spaces were suddenly filled to their maximum extent and the normal anatomical barriers then ruptured. This is certainly an artificial state of affairs for in the living subject, the normal anatomy is progressively altered as reaction to infection proceeds, and pus never appears suddenly but is formed gradually As has been pointed out in Section 1 the principal objective of the defence mechanism is the creation of an inflammatory barrier to surround and localize the invading organisms. In the hand as this barrier is set up the inflammatory changes seal off the potential tissue spaces and the adjacent structures become adherent to one another The surgeon should therefore give more consideration to the inflammatory than to the anatomical barrier In hand infections as elsewhere it is a sound general principle to delay surgical intervention till adequate localization has occurred.

Course of Infection in Special Sites

Special consideration must be given to the pathology of pulp infections and of infective tenosynovitis in relation to early incision.

Pulp Infection. If a pulp infection is treated expectantly by the application of heat *and by the administration of parenteral penicillin, in a considerable proportion of cases* the initial cellulitic phase subsides without suppuration and complete resolution occurs. In the majority however localization with suppuration occurs and a tough slough forms at the site of maximum incidence of infection. This slough softens with the formation of pus which in turn tracks towards the surface and presents either terminally centrally or laterally *This abscess is of the collar stud type The base of the stud is* the cavity containing the slough, the neck points through the dermis and the top of the stud is a purulent subepithelial blister If during this period the terminal phalanx is X-rayed it will be found that progressive decalcification is taking place and these changes have often been regarded as indicating that the bone has undergone necrosis But if expectant treatment is adopted, it is seen that in the course of time recalcification occurs and weeks later this usually restores the bone to an almost normal appearance (Fig. 5) This is surely evidence that the initial bone changes were due to active hyperaemia and not to compression of the blood supply to the shaft of the phalanx. Thus the main reason for advocating early incision in pulp infection, viz. the danger of necrosis of the phalanx due to tension, is not soundly based.

Tendon Sheath Infection. The reaction of the synovial lining of the tendon sheath to infection is similar to that of any other serous lining such as the peritoneum or pleura.

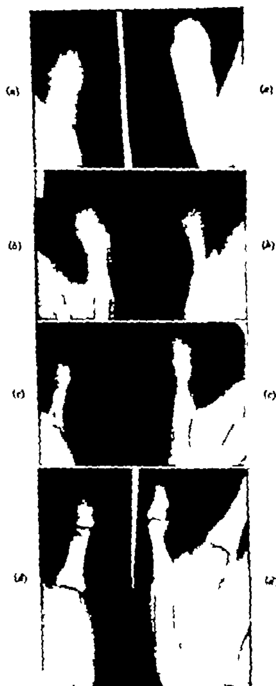


Fig. 5 (a) Radiograph of termin
case of pulp infection of the thu
duration. There had been no
vention. Considerable rarefacti
affecting all but the cortical laye
aspect. (b) Radiograph taken
showing increased rarefaction
phalanx, although by this time t
of the thumb was satisfactory
employed was conservative, with
of slough, and without any i
( ) Radiograph taken 19 days l
cation of the phalanx is occurrin
infection had subsided, and t
healed. (d) Radiograph taken
showing complete recalcification
phalanx, except for extreme tip

(From British Journal of Surgery, John
Ltd Bristol)

Infection of the sheath is followed immediately by widespread effusion. There is tender ness and swelling along the line of the sheath and limitation of function. Next, the layer of the synovia become adherent around the point of entry of the infection, the effusio in the sheath is partly absorbed and around the site of entry the usual inflammator barrier is built up This barrier spreads out from the level of the sheath to the mor superficial tissues and eventually involves the skin. If the defence mechanism is weak, th

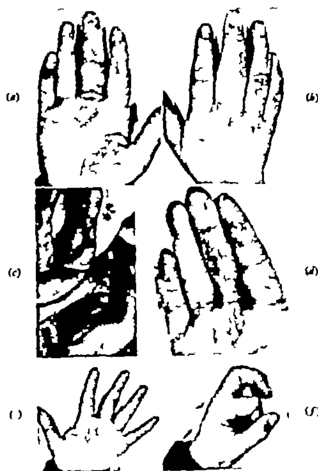


FIG. 6. Case of suppurative tenosynovitis treated initially by local heat and rest and parenteral penicillin. (a), (b) Show palmar and dorsal aspects of middle finger with localization over the proximal inter phalangeal joint. (c) Shows the abscess opened by removing the outer wall. Tendon lies exposed in the depths. (d) The same case 4 weeks later. The wound is already healed and the patient had returned to work as a bus conductress. (e), (f) Show the finger 11 weeks after operation. The scar is well healed and function is good.

(From British Journal of Surgery, John Wright & Sons, Ltd Bristol)

barrier remains broad and ill defined and may spread from the site of infection both proximally and distally If the defence is adequate the barrier becomes narrow and well defined. The clinical evidence of the latter outcome is that the area of redness, swelling, and tenderness becomes localized and finally may show central pus formation. This pus will eventually be extruded through the skin on the palmar surface of the finger and usually near the level of the proximal or distal interphalangeal joint (Fig. 6 (a))

As localization occurs, the signs of infection in the sheath, proximal and distal to this point, disappear and function improves, although there is still pus in part of the sheath. Now is the time for surgical intervention, when the road to the surface has been well walled off If this abscess is opened by removing the purulent blister and widening the

neck of what is again a collar stud abscess, it will be found that the wall of the fibrous tunnel and the synovial sheath have been penetrated and the tendon lies exposed. That the cavity of the sheath has been closed proximally and distally can be demonstrated by attempting to pass a probe along it. The probe is arrested at the level of the abscess wall where the layers of the sheath have become firmly adherent (Fig. 6 (*c*))

Had the sheath been opened widely in the early stages the inflammatory barrier would have been damaged, the blood supply to the infected part restricted and the spread of infection encouraged

Scars on the Palmar Aspect of the Fingers In the past there has been a bias of surgical opinion against scars in the palmar aspect of the pulp and proximal parts of the fingers. Under aseptic conditions an incision for a non-pyogenic lesion of the finger is probably best placed laterally In draining an abscess, however additional factors must be taken into account Often the lateral incision provides less direct drainage, traverses uninfected tissue and traumatizes the inflammatory barrier in entering the abscess. Further if there be any delay in healing, scarring and contracture may involve the very vessels and nerves the incision was designed to protect The lateral incision loses much of its attraction when it is realized that many of the evils ascribed to scars on the palmar aspects of the fingers are unwarranted If infections in the subcutaneous tissues, in the pulp and in the tendon sheaths of the finger are treated expectantly many will result in pus formation and this pus will track to the palmar surface. When this stage is reached direct drainage can be established without fear that the resulting scar will be a serious handicap (Fig. 6 (*e*), Fig. 8 (*d*))

The Frozen Hand. This title seems an appropriate one for a clinical state fortunately rare The condition may follow a severe palmar infection, or less commonly a dorsal subaponeurotic abscess. In the affected hand, even after an apparently satisfactory subsidence of the active infection, the inflammatory œdema not only persists but increases and spreads to involve the fingers, hand, and wrist. The œdematous hand is tense but not tender and function is grossly limited. Radiological investigation frequently shows a progressive decalcification of metacarpals, carpal bones, and lower ends of the radius and ulna. Before the swelling subsides, function is restored to near normal and recalcification of bones occurs, weeks or even months may elapse The etiology of this condition is obscure but the effects are probably the result of persistent or widespread hyperæmia. Active exercises under supervision are the most effective form of treatment.

Principles of Treatment

The principles already enunciated for the treatment of pyogenic infections in general apply to the treatment of hand infections. Certain modifications are of value, according to the site and nature of the infection and these will be noted in dealing with the treatment of individual lesions. In general, however now that we have the aid of the antibiotics the treatment should be expectant In the initial stages, while the inflammatory reaction is active and localization has yet to occur the hand should be put at rest, heat applied locally and sedation given. Penicillin should be administered either parenterally in aqueous solution or long acting form, or orally The duration of treatment with penicillin is judged solely by the clinical state and it should be discontinued whenever localization has occurred. Lymphangitis and lymphadenitis should be regarded as specific indications for penicillin therapy In a proportion of cases resolution without suppuration

Infection of the sheath is followed immediately by widespread effusion. There is tenderness and swelling along the line of the sheath and limitation of function. Next, the layers of the synovia become adherent around the point of entry of the infection, the effusion in the sheath is partly absorbed and around the site of entry the usual inflammatory barrier is built up. This barrier spreads out from the level of the sheath to the more superficial tissues and eventually involves the skin. If the defence mechanism is weak, the

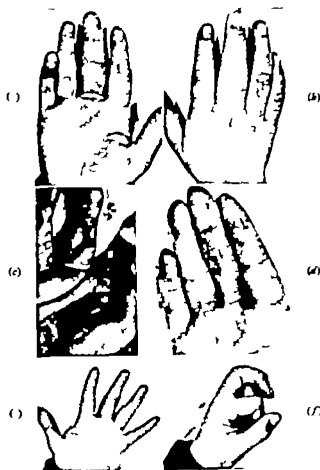


FIG. 6. Case of suppurative tenosynovitis treated initially by local heat and rest and parenteral penicillin. (a), (b) Show palmar and dorsal aspects of middle finger with localization over the proximal interphalangeal joint. (c) Shows the abscess opened by removing the outer wall. Tendon lies exposed in the depths. (d) The same case 4 weeks later. The wound is already healed and the patient had returned to work as a bus conductress. (e), (f) Show the finger 11 weeks after operation. The scar is well healed and function is good.

(From *British Journal of Surgery*, John Wright & Sons, Ltd., Bristol.)

barrier remains broad and ill defined and may spread from the site of infection both proximally and distally. If the defence is adequate the barrier becomes narrow and well defined. The clinical evidence of the latter outcome is that the area of redness, swelling, and tenderness becomes localized and finally may show central pus formation. This pus will eventually be extruded through the skin on the palmar surface of the finger and usually near the level of the proximal or distal interphalangeal joint (Fig. 6 (a)).

As localization occurs, the signs of infection in the sheath, proximal and distal to this point, disappear and function improves, although there is still pus in part of the sheath. Now is the time for surgical intervention, when the road to the surface has been well walled off. If this abscess is opened by removing the purulent blister and widening the

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will occur and this in itself is a further argument against early incision. The earlier treatment is initiated the greater the chance of resolution without suppuration. If localization with suppuration is the outcome a collection of pus forms and the abscess should be evacuated by the most direct route. Most collections in the fingers and hand take the form of collar stud abscesses. These can be opened as part of the dressing *technique and without anæsthesia. The epithelium raised as a purulent blister is cut* away and the neck of the abscess gently enlarged with sinus forceps. If it seems desirable to remove an adherent slough from the deep part of the abscess, operation is best carried out under light general anæsthesia. The roof of the deeper part of the abscess is removed and the slough cut away (Fig. 8) If given time, however the vast majority of such sloughs will separate spontaneously The treatment described has the great merit of simplicity requires no special surgical facilities, and demands anæsthetic aid only rarely In practice it is outstandingly successful.

Tourniquets and Local Anæsthesia. Experimentally produced ischæmia does more to promote bacterial growth in tissue than anything else. This suggests that the use of tourniquets and local anæsthetics, which reduce the blood supply to the infected part, is far from ideal. On occasion, however a surgeon or practitioner may be forced by circumstances to employ them.

Drainage Tubes. With the possible exception of some dorsal subaponeurotic collections, abscesses in the hand should never be drained.

Dressings. *Before the discharge of pus, heat is best applied in the form of kaolin* which has the additional advantage of acting as an adequate splint.

When pus has been evacuated either spontaneously or following operation, moist dressings in the form of gauze wrung out of eusol, proflavine, or antibiotic solution, are useful. The dressings should be adequate, firmly applied and the fingers bandaged individually Dressings should not be renewed too frequently the surgeon being guided in this by the amount of discharge.

The use of a sling in the early stages is of paramount importance.

Exercise in Regaining Function. Prior to resolution or localization, rest is essential in the management of hand and finger infections. Once satisfactory localization has been achieved and often before a collection of pus has been evacuated, it will be found that the patient is free of pain and is both willing and able to move the finger and hand. Active movement of the whole hand and of individual fingers should now be encouraged. These movements must be purposeful and sustained and should include flexion at each *interphalangeal joint as well as at the metacarpo-phalangeal joints. The interossei* should be exercised by abduction and adduction of the fingers. These exercises should be supervised at the time of dressings. Passive movements, especially if they cause pain, should be discouraged.

Though the infection may be confined to one finger it is most important that the function of the remaining fingers of the hand should not be forgotten. The result of treatment of any hand lesion will be judged by the function of the hand as a whole, just as much as by the function of the affected digit. It may on occasion be worth sacrificing a single digit, or part of it, in order to preserve the function of the hand.

Lastly the surgeon should remember that in any finger which has become stiff as a result of infection, no matter how long ago, manipulation under anæsthesia is likely to do more harm than good.

Classification of Hand Infections

navel set the fashion of classifying hand infections according to the anatomical rtment involved and advocated surgical drainage of these compartments by mical" approaches. With the advent of the antibiotics a more expectant line of ent has been adopted. This in turn eliminates the urgent need for accurate diagno- he exact site of infection. Consequently a more practical clinical classification is d. The suggested classification is given in the form of a table

	Of the Finger	*Of the Hand*
Infections on the dorsal aspect	Paronychia Subungual abscess Nail fold Subepidermal Erysipeloid Hair follicle (carbuncle)	Hair follicle (carbuncle) Subaponeurotic
Infections on the palmar aspect	Pulp Subcutaneous Tendon sheath	Superficial < Distal / Proximal Deep < Distal (Web) / Proximal (Palmar space)

e primary division of infections into those on the dorsum and those on the palmar is made because, with the possible exception of the subaponeurotic abscess, ssue infections on the dorsum are unlikely to result in permanent damage to on. It must be borne in mind that a penetrating injury on the dorsum, which in infection of an interphalangeal or a metacarpo-phalangeal joint, may be ed by septic arthritis and loss of function. A common example of this latter type ury is the penetration of such a joint by a tooth when the clenched fist strikes a on an opponent's mouth.

ections on the palmar aspect of the hand are found in practise to arise from two of injury. In the palm proximal to the distal transverse crease infection is in- ly due to a penetrating wound, and depending on the depth of penetration the on is superficial or deep to the palmar aponeurosis. In the palm, distal to the erse crease, the causative injury results from friction or pressure. Examples of this f injury are found in the case of the non-manual worker who grasps and uses for a ged period a handled tool, such as a pick, who cranks a car or who exceeds his limit at golf. It is also found in the manual labourer using a new tool, the shaft of is not well adapted to his hand. If the main brunt of pressure and friction falls ical to the prolongation of the palmar fascia extending into the fingers, the int lesion is a superficial blister. If the infection is deep to these prolongations ny collection which forms points in the finger web

Dorsal Infections

Paronychia. This term means infection around the nail but it is best reserved fections involving the edge or base of the nail bed. It may occur as a single acute ion but is more commonly recurrent.

The *acute* variety is always due to the pyogenic organisms and arises as a tender reddened area at the junction of edge and base of nail. Sharp sickening pain is experienced if the surface of the nail is pressed upon, or if the distal edge of the nail is thrust proximally As the condition develops a little bead of pus appears under the edge of the nail and nail fold.

Treatment is expectant, with the local application of kaolin. When the bead of pus develops and discharges, dressings of penicillin or chlortetracycline ("Aureomycin") cream may result in complete resolution If pus continues to collect under the nail, the nail should be removed (Fig. 7) Partial removal of the nail has been advocated but it is easier to remove the whole nail and so ensure adequate drainage The resulting



(*a*) (*b*) (*c*)

FIG 7 *Removal of Nail in Chronic Paronychia* (*a*) Infection of base of nail. (*b*) Nail split longitudinally and each half removed in turn. (*c*) Nail fold excised.

clearance of infection allows quick epithelialization of the nail bed, with freedom from tenderness. When the whole nail has been removed the new nail is often more normal in appearance than that following partial removal.

The *recurrent* type is most frequently due to pyogenic organisms but on occasions is the result of fungal infection In pyogenic infection antibiotic creams can be given a trial and will frequently give prolonged remission. In the end, removal of the nail is usually necessary

Yeast (*Candida albicans*) infections are characterized by chronicity the development of an area of brown discoloration at the side of the nail and the scanty discharge of mucoid rather than purulent material. Treatment is by the application of gentian violet or carbol fuchsin The nail may need to be removed to give adequate drainage and to bring the fungicide into direct contact with the infected area X ray therapy can be used as an adjuvant to these methods of treatment.

Infection of the nail by ringworm fungi is the least common form of paronychia Usually the distal part of the nail is involved but unfortunately as the nail grows the infection spreads proximally keeping pace with the growth. The affected nail is thickened,

ridged, and fissured. Diagnosis is confirmed by demonstrating the fungus on microscopic examination of scrapings from the nail. Treatment should in the first place be the application of fungicides. If this is unsuccessful after thorough trial then the nail should be removed and the application of fungicides continued.

(2) **Subungual Abscess.** This describes a collection of pus under the nail. It may arise in association with paronychia or as the result of some injury such as a splinter running under the nail. The treatment is removal of the nail.

(3) **Nail-fold Infection.** Infection in the nail fold is met with in nail biters when it is often caused by coliform bacilli. It also occurs in association with paronychia. It may be due to a little portion of skin or cuticle being torn and infection with staphylococci or streptococci supervening. It is under those circumstances that lymphangitis commonly results. When lymphangitis occurs the streptococcus is frequently to blame, but staphylococcal infection can also cause it.

If the infection of the nail fold is associated with paronychia, treatment is along the lines indicated for the latter condition. If infection is limited to the nail fold, it should be treated expectantly. Resolution is frequently complete but if suppuration occurs the purulent blister formed can be opened with stitch scissors.

(4) **Sub-epidermal Infection.** This is not common. The causative organism is most frequently the streptococcus. Infection arises in the epidermal layer of the skin overlying the dorsum of the middle phalanx. It spreads irregularly in the epidermis of the finger raising that layer in purulent blisters which rupture shedding the epidermis and leaving extensive raw red areas. These areas are painful and tender and discharge serosanguineous and purulent fluid. Treatment consists in the local application of antibiotic creams—the most effective being chlortetracycline ("Aureomycin") and penicillin. Occasionally when a mixed infection is responsible, one of the organisms is insensitive and the condition becomes chronic and resistant to treatment.

(5) **Erysipeloid of Rosenbach.** The causal organism of this unusual infection is *Erysipelothrix rhusiopathiae*. This rod-shaped bacillus, non-motile and non-spore bearing, is found in decomposing nitrogenous material. The most common clinical lesion is a localized cutaneous infection and it is usually seen in the fingers, hands or forearms of those working with fish or meat.

Two to three days after a minor injury to the finger with a fish or meat bone, the patient complains of itching, smarting and stiffness in the affected part. Severe pain and tenderness are unusual. Around the area of the injury is an erythematous patch with a distinct raised edge and of a colour varying from pink to purple. Occasionally there may be numerous patches in the one patient. Systemic disturbance is minimal.

The lesion will heal spontaneously but may take up to 3 weeks to do so. If treatment with parenteral penicillin is initiated early then the infection should subside within 4–6 days. Recrudescence of infection is not uncommon and a second course of penicillin may be required.

(6) **Hair Follicle Infections of Finger and Hand.** These lesions can occur wherever hairs are found but are most frequent over the dorsum of the proximal part of the finger and the ulnar margin of the hand. Infection is presumed to result from minor trauma. The invading organism is invariably the *Staphylococcus aureus*. Lymphangitis and lymphadenitis are not uncommonly associated with these lesions. While the infection may be trivial and remain confined to one follicle, spread to other follicles with a resultant

carbunculous lesion is frequent. The condition has the appearance as well as the local and general clinical effects, of a carbuncle elsewhere Treatment consists of the administration of penicillin the local application of kaolin and immobilization of the hand in a sling. When discharge commences a moist eusol dressing is applied locally and attention can be turned to exercises.

(7) **Subaponeurotic Infection.** This denotes infection deep to the fascial expansion overlying the extensor tendons on the dorsum of the hand. Infection can arise by spread from a carbuncle on the dorsum, by penetrating injury or on rare occasions, by dorsal spread between the metacarpals from an extensive deep infection in the palm. The most common infecting organism is the *Staphylococcus aureus* and thus the usual lesion is a suppurative one Frequently a large abscess is produced and it has to be drained by deliberate incision under general anaesthesia. Incisions should be made just to the radial side of the extensor tendon to the index finger and on the dorsal aspect of the ulnar border of the hand These incisions together provide adequate drainage. A rare complication is the development of prolonged oedema of the hand, already referred to as "frozen hand."

Infection may also be due to the streptococcus when an acute cellulitis is produced. If treated expectantly the condition usually resolves and only occasionally will suppuration occur

Two more conditions should be mentioned under this heading, of which the first is relatively common The patient strikes the tooth of an opponent with his closed fist and receives a penetrating injury of the metacarpo-phalangeal joint, usually of the middle finger This may result in a pyogenic arthritis, damage to the extensor expansion of the finger and a subaponeurotic space infection.

The second condition is extremely rare. A penetrating injury of relatively minor character on the dorsum of the hand results in air being sucked into the subcutaneous tissues with certain movements of the hand. This produces surgical emphysema with all the characteristic signs and if it is associated with mild infection may result in a diagnosis of gas gangrene by the unwary The patient, however shows none of the constitutional upset that would be expected with such an infection Appropriate treatment for the infection, together with adequate splintage, will lead to resolution.

Infections on the Palmar Aspect of Fingers and Hand

(1) **Pulp Infection.** The pulp of the finger is the soft tissue overlying the palmar aspect of the distal phalanx. Infection in this situation is, therefore, similar to subcutaneous infection elsewhere, but it is modified by certain special features. The skin is bound to the periosteum of the phalanx by strands of fibrous tissue and thus the capacity of the subcutaneous space is limited. This results in a quick rise of tension when the inflammatory exudate is poured into the tissues. The tension, however does not rise to such a level as to obliterate the arterial supply to the phalanx (*see* page 20, section on Course of Infection in Special Sites, and Fig. 5). The intense throbbing pain in pulp infections has often been attributed to this rise in tension. No doubt tension is a factor but the prime reason for the severe pain is the fact that the pulp is alive with sensitive nerve endings and these are irritated and constantly stimulated by the inflammatory reaction.

Infection gains entrance by means of a penetrating wound of minor type sometimes

the patient cannot relate the infection to any known trauma. The invading organism is most frequently the staphylococcus.

Clinically the patient first notices localized pain and tenderness at one point in the pulp. In a short time the pulp becomes swollen red, tender and painful. The pain is of throbbing character and most noticeable when the hand is dependent

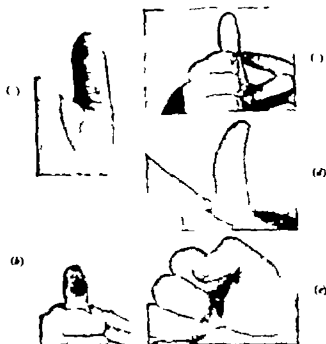


FIG. 8. *Pulp Infection* (a) Infection is localized with formation of collar stud abscess. (b) Pulp infection of thumb, showing saucerization method of opening the pulp after complete localization had occurred (c) Same case 4 weeks later The thumb had healed 10 days prior to this and the patient had returned to his job as a school-teacher (d), ( ) Same case 16 months later showing a well-healed non-tender scar in a pulp only slightly flattened Full function is present.

(From British Journal of Surgery, John Wright & Sons, Ltd Bristol)

If conservative treatment is instituted early many of these cases will resolve without suppuration (23 per cent—Gordon) In the remainder suppuration takes place with the formation of a localized abscess.

Once a localized collection of pus has formed the abscess can be deliberately incised under anæsthesia (Fig. 8). It is also quite justifiable to delay further and open the abscess with scissors as part of the dressing technique or finally the abscess can be left to discharge spontaneously The healing time is little different whichever method is employed.

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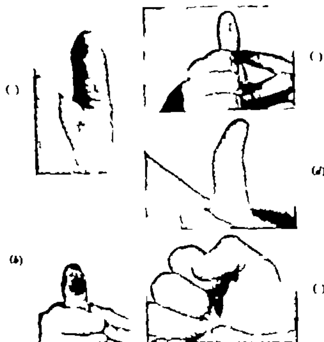


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pulp infections treated by the expectant method only eight patients suffered loss of the terminal phalanx and six more the disability of a stiff terminal inter phalangeal joint (Gordon) Infrequently infection spreads directly to the tip or more of the terminal phalanx and the involved bone sequestrates (Fig. 5). Spread to the distal interphalangeal joint will lead to a pyogenic arthritis resulting either in loss of the terminal portion of the finger by amputation or a stiff joint. Lastly infection may involve the distal part of the synovial sheath of the deep flexor tendon or the attachment of the tendon to the base of the terminal phalanx, with usually some permanent impairment of movement in the distal interphalangeal joint.

(2) **Subcutaneous Infection of the Finger and Palm.** In the fingers this includes infections of the tissues overlying the palmar aspect of the first and second phalanges, but superficial to the tendon sheath. In the palm it includes infections superficial to the palmar aponeurosis. These infections are usually of a minor character and if treated expectantly superficial purulent blisters form. These are opened and the infection rapidly subsides. There is a very serious though fortunately rare complication which is seen in association with subcutaneous infection of the fingers. It is bacterial gangrene. Infection is so severe, and local reaction so intense that thrombosis occurs in the digital vessels with resultant gangrene of the distal portion of the infected digit. Amputation is the only effective line of treatment.

(3) **Infection of the Flexor Tendon Sheaths.** The pathology of this condition has already been discussed. The causative organism is invariably the staphylococcus and entry is gained by a minor penetrating injury Following infection the patient becomes aware of pain and stiffness of the finger The finger is swollen and red on its palmar aspect and is held in slight flexion Active movement is restricted and any attempt at passive movement is resented. This clinical picture applies equally well to the more severe and widespread subcutaneous infections and the differential diagnosis is far from easy Some help in distinguishing those cases which have true tendon sheath infection is gained by the fact that in tenosynovitis the tenderness is restricted to the line of the sheath and extends along the sheath into the distal part of the palm. Even this finding is not conclusive for it should be borne in mind that the sheath may react by producing an effusion within its lumen when adjacent to a severe superficial infection. This is comparable to the synovial effusion in the knee joint when osteomyelitis is active in the lower femur This difficulty of accurate diagnosis is a sound reason for initial conservative treatment. If the surgeon resorts to early incision he may well open the sheath through infected subcutaneous tissues and so infect the sheath unnecessarily

A further point is that incision into the lateral aspect of the sheath, especially if done roughly may damage the synovia (vinculæ) lying between the tendon and the phalanges, thus destroying part of the blood supply and promoting adhesion between tendon and bone. Fixation of the tendon rather than sloughing was responsible for many of the stiff fingers that were so frequently the outcome of treatment in the past.

Treatment The method of treatment to be described has the great merit of simplicity It requires no special surgical facilities and its results, although not perfect, are reasonably satisfactory In a reported series of fifty-two cases, thirty-eight recovered full function of the finger and hand while, despite a poor "finger" result, nine more recovered good general function of the hand (Gordon).

If there is no sign of a localized collection of pus when the patient is first seen, the

usual expectant treatment is initiated. Antibiotic therapy is combined with the application of kaolin locally and the use of a sling. Sedation is usually required. With this treatment many cases suspected of having tendon sheath infection of the finger will resolve completely without suppuration and with no surgical intervention.

In the remaining cases suppuration occurs. A localized abscess forms and points, most commonly in the crease overlying the proximal interphalangeal joint (Fig. 6 (*a*)). At this stage the patient's general and local condition is greatly improved. Swelling of the finger is reduced and some degree of active movement without pain can be achieved. The abscess can now be opened either deliberately under anæsthesia or by snipping the blister with scissors (Fig. 6 (*b*)). At this stage the true depth of the infection can be ascertained. The infection may be at one of three levels:

(1) Superficial to the fibrous tunnel containing the tendon and its sheath, i.e. a subcutaneous infection.

(2) In the space between the fibrous tunnel and the synovia.

(3) In the lumen of the synovial sheath itself.

After evacuation of the abscess, active exercises are begun and recovery is usually rapid and complete. The wound should be healed and the patient fit for full work within 28 days from the onset of the infection.

The most common complications that may follow this form of infection are sloughing or fixation of the tendon, resulting in a stiff finger. The nature of the patient's occupation will determine whether amputation is to be recommended. Another complication is extension of infection to the phalanges or to the interphalangeal joints, and conservative treatment will at best produce a stiff finger. It may, therefore, be wise to sacrifice the finger, or part of it, at the stage when osteomyelitis or pyogenic arthritis is definitely diagnosed.

(4) Infection of the Palm

(*a*) Superficial

Infections superficial to the palmar aponeurosis and distal to the transverse crease are invariably associated with the raising of a blister by friction. The blister becomes purulent and treatment consists of cutting away the dead skin.

Superficial infection proximal to the transverse crease can arise following either a friction or a penetrating injury. In either case, if suppuration occurs, the resulting collection of pus usually discharges spontaneously. If necessary it can be deliberately evacuated.

(*b*) Deep

Infection arising in the palm, deep to the tough palmar aponeurosis is more serious. It responds well, however, to modern methods of treatment and complete recovery of function should be the rule.

The palmar space, or more correctly potential space, is the area bounded anteriorly by the palmar aponeurosis and posteriorly by the metacarpals with the attached interossei and transverse head of the adductor pollicis, these muscles being covered by fascia. Traversing this space are the flexor tendons of the finger and thumb, enclosed in their synovial sheaths, the deep branch of the ulnar nerve and the deep palmar arch. The space is filled by loose areolar tissue. Proximally via the carpal tunnel, the space

is in continuity with a similar space in the forearm, often associated with the name of Parona. It is bounded anteriorly by the flexor muscles and dorsally by the radius and ulna overlain by the pronator quadratus.

Despite the possibilities of extension of infection by these anatomical routes and the proximity of structures vital to function, infections in the palm rarely result in

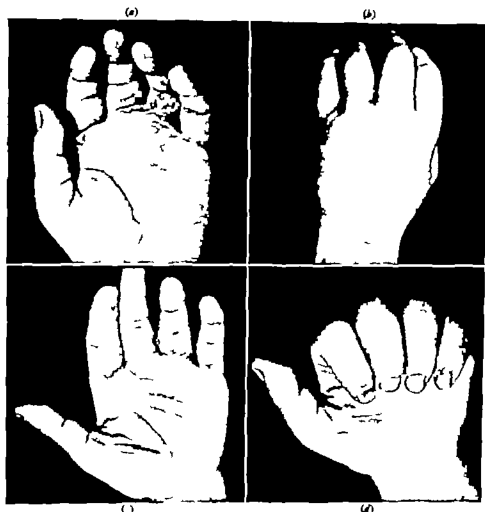


FIG. 9 *Deep Palmar Infection (Distal)* (*a*) Infection localized in web (*b*) This shows associated swelling on dorsum of fingers and hand. (*c*), (*d*) One week later Spontaneous discharge has taken place with rapid healing and return of function.

permanent disablement Infections in the pulp and palmar aspects of the fingers, with the easier access of infection to tendon sheath, bone, and joint, are more liable to result in loss of tissue or in permanent disability

(1) DISTAL. As already stated, infection deep to the palmar aponeurosis and distal to the transverse crease, usually follows some form of friction injury After some unaccustomed manual exercise such as rowing, or cranking a car the patient develops

superficial blisters overlying the metacarpal heads Twenty four or forty-eight hours later he becomes aware of deeper seated throbbing pain in the region of the base of one or more fingers. This is accompanied by increased swelling and redness at that site. *Function* of the affected hand and digit is greatly reduced (Fig. 9)

Expectant treatment should be instituted and within 48 hours resolution or localization will have occurred If the latter the resulting collection of pus points in the web and again can be allowed to discharge spontaneously or deliberately evacuated. In either case function is rapidly restored and the wound heals quickly

(2) PROXIMAL. Deep palmar infection proximal to the transverse crease is invariably the result of a penetrating injury Infection sets in on an average 2–3 days after injury The hand and fingers become swollen, stiff and painful. The palmar hollow is filled out and tenderness is maximal there (Fig. 10 (*a*)). Before resolution begins the swelling and *tenderness may spread to the palmar aspect of the wrist and lower forearm. In addition,* in the more severe infections, oedema of the dorsal aspect of the hand becomes gross. This may lead the unwary surgeon to seek pus by incising the dorsum (Fig. 10 (*b*))

Parenteral penicillin is given and the arm is put at rest in a sling. Kaolin is applied to hand and forearm and the necessary sedation prescribed. Both patient and surgeon may spend an anxious 72 hours, during which the symptoms and signs persist or become intensified. Thereafter the clinical signs begin to subside and finally become localized to the region of the wound in the palm. The hollow of the palm remains ballooned and tenderness may be acute. By this time the wound is *probably discharging and if a collection has*

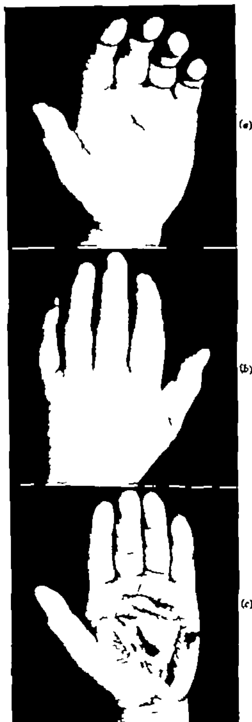


FIG 10 *Deep Palmar Infection (Proximal).* (*a*) Infection localized with formation of purulent blister superficially and abscess formation deep to palmar fascia. (*b*) Associated oedema of the dorsum of the hand is illustrated ( ) Purulent blister has been removed and deep abscess evacuated by enlarging track of original penetrating wound.

formed it can be evacuated by enlarging the opening in the palmar aponeurosis made by the original injury (Fig. 10 (c)). Now is the time to institute active exercises. Restitution of function and quick healing of the wound should follow.

Persistence of œdema and the development of the condition earlier described as the "frozen hand" is a rare complication.

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CHAPTER II

ACCIDENTAL WOUNDS AND THEIR MANAGEMENT

P S LONDON

INTRODUCTION

A WOUND is usually thought of as a breach in the surface of the skin or the mucosal lining of a body cavity but this conception can be logically extended to include the interruption of continuity of any tissue Depending on whether or not the air has access to the wound it may be open or closed. This distinction is of basic importance for the open wound is a prey to infection, the risk of which increases with the time that the wound remains open and, more so with the time for which it is exposed Infection of the closed wound is exceptional but may occur as the result of penetration of damaged skin by pathogenic organisms (Sevitt, 1953) or by metastasis from an existing focus such as a boil, tonsillitis, or an infected wound elsewhere.

Healing occurs most rapidly and effectively—truly by first intention—when healthy surfaces are maintained in close apposition for then the reparative process is unhampered

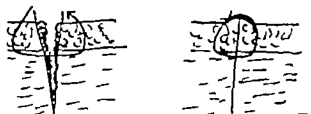


FIG. 11 Closure by simple suture after superficial trimming. Deep stitches are not necessary in many such cases.

by blood clot or dead tissue and has only a very narrow cleft to span (Fig. 11) Such conditions are found typically in incised and stab wounds and wounds of this nature have been classed by Rank and Wakefield (1953) as "tidy " They also include the clean-cut injuries resulting in loss of skin, e.g. slicing wounds and scalping, or other tissues, as in some traumatic amputations. Though one wound surface has been lost it can readily be restored by suitable trimming and the fashioning of flaps or the use of skin-grafts (Fig. 12)

The "untidy" wound results from shearing, crushing, or tearing and is characteristically caused on the roads when a part is run over or in the factories when a limb is caught in machinery Bursting wounds caused by gun-shot are also untidy The forces applied not only crush, split, and tear the various formed structures but force them apart, so rending the intervening planes of connective tissue. Tissues injured in this way may die early as a result of the force applied directly to them or because their blood-supply has been cut off by arterial damage or they may die later from progressive local circulatory embarrassment or because of infection. Many blood vessels are torn and widespread bleeding occurs into and between the formed tissues with consequent swelling and rise

of pressure (Fig. 13) Anoxia and increasing permeability of small vessels abet the pr of vascular compression, stasis, and thrombosis and the final balance between surv and dead tissues may not be struck until long after the completion of primary treat Thus even with tissues that are exposed there is no guide to their viability and closed wounds of comparable complexity only very rough and necessarily ten estimates of the extent and severity of the damage can be made from the circumst of injury the amount of swelling and the radiographic appearances.

In untidy wounds, then, there is inevitably some dead tissue and blood-clot v has to be disposed of and even without infection final healing of the whole wou delayed and function may be seriously and permanently impaired by scarring and ness. However there are other causes of slow healing and a trivial wound will careful treatment if the tissues be embarrassed by arterial disease of any kind, by gra tional venous stasis and oedema or by some of the neuropathies. Not uncommon is the slow healing of a wound that leads to recognition of such conditions

In addition to these general considerations some wounds have special features will be dealt with later

MANAGEMENT

With large wounds, the general effects of injury including shock, have to be with as well as the local condition and it is important to realize that without loss drop of blood externally a person can bleed to death into the extensively torn tissues around severe, multiple fractures (Clarke and others, 1955) If as is not common, there be associated injuries of the chest and belly the treatment of s becomes a matter of urgency

PRELIMINARY MEASURES

Any clean cloth will suffice as a first-aid dressing but as soon as possible an wound should be covered by an occlusive dressing of sterile, dry gauze and a thick l of sterile wool kept in place by a firm bandage and supplemented in appropriate c by plaster or other splintage. As the object must be to reduce the risks of contamina detailed examination should be deferred until the patient has been moved to operating theatre, but distorted skin flaps should be gently straightened out and lai place before the dressing is applied.

Definitive surgical treatment should be carried out as early as possible for two reas firstly to remove the culture media provided by blood clot and dead tissue before r contamination has become active bacterial invasion and secondly to restore skin f to their normal tension before retraction and possible kinking have led to the swel that both impedes the circulation and complicates closure. If necessary resuscita be started promptly and carried on with determination, even the badly injured usually be made fit for operation within a very few hours.

DEFINITIVE TREATMENT

TIDY WOUNDS. The emphasis falls on repair and closure and often there is the skin to be dealt with. Formal block excision should not be carried out and sufficient to remove only damaged edges and tags of tissue If a main artery has b damaged and can be repaired this should be one of the first steps after the wound

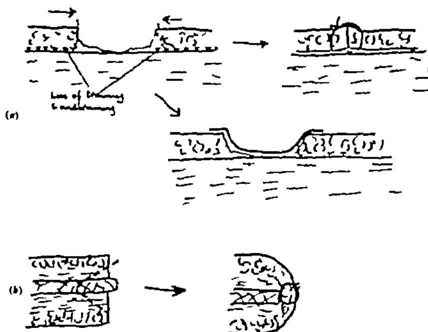


Fig. 12. (a) Closure of defect by suture after undermining and simple advancement or by grafting. (b) Closure by trimming and the use of flaps.

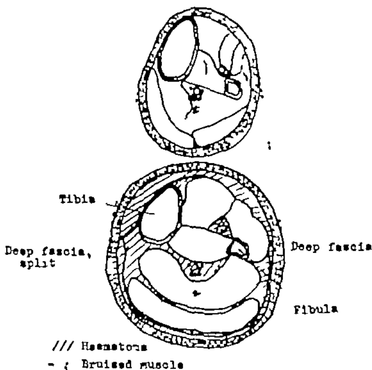


Fig. 13 To illustrate the disruptive effects of crushing. As well as being torn from its fascial moorings the skin is usually badly bruised and though shown intact here it has more commonly been split. The amount of swelling has been slightly exaggerated

been explored (Fig. 14) and if nerves are to be sutured it is an advantage to be able to deal with them too while the surgeon is still fresh, but there are other considerations. An unstable fracture should be reduced and, if necessary fixed first so that suture-lines shall be spared the stresses and strains of manipulation. Similarly the preparation of a suitable bed and the repair of underlying structures will often be more easily carried out before suture of a vessel or nerve

Primary suture of nerves is a vexed question. Secondary suture is generally advised for accidental injuries on the grounds that it is technically easier and the size of the



FIG. 14. Suture of the ulnar artery and approximation of the median nerve after very deep, tidy wound of the upper part of the forearm Radial and ulnar arteries, median and ulnar nerves had been divided.

neuroma indicates the extent of resection required Nevertheless in good hands primary suture has its successes provided the cases are selected carefully there must be assurance of prompt healing without infection cleanly and transversely divided ends without intraneural hæmorrhage a good bed for the suture line (this may call for transplantation of the nerve) and no tension. Youth is an advantage but even with all these favourable conditions suture should be delayed unless the nerve has been cut near its termination. After primary suture at the wrist, for example it is soon evident whether recovery is occurring or not and if not secondary suture can still be carried out before the short distal sheaths will have shrunk enough to impair conduction by the regenerated axons (M R.C. 1955).

As a general rule, functionally important (and viable) muscles and tendons should be retained, and repaired if necessary A muscle that has been split along the line of its fibres does not require stitches for the split will be closed effectively by sewing up the skin and applying a firm pressure dressing, but a muscle that has been cut across should be sewn up with the twofold object of restoring function and obliterating dead space.

If its blood-supply has been cut off however a muscle or group of muscles should be excised and, according to circumstances, any remaining tendons may be removed, left free or attached either to a suitable motor or to bone to act as a tenodesis (Parkes, 1951) Stiffness and deformity that increase after damage to muscle or to the main blood supply of a limb may be due to ischæmic contracture and call for excision of the infarct (Seddon 1956) (Fig. 15) Tendons should not be repaired at the first operation if they



FIG. 15 Contracture following accidental, tidy division of the brachial artery (ligated) and median and ulnar nerves above the elbow

have been cut in the "dangerous area" of the digital sheaths or if there be a risk of infection.

Complete repair along these lines can be a lengthy and taxing procedure, not only for the surgeon. The patient may have suffered multiple injuries and be in poor general condition so that speed and simplicity become more important than completeness. It is a tragedy to have to amputate a limb that might have been saved in less urgent circumstances but it is a decision that has to be faced from time to time. If however the question should arise principally because a main artery has been severed, an attempt should be made to repair at least this, leaving the skin to be closed a few days later Other structures can be dealt with when the wound has healed soundly and the tissues are becoming pliable.

UNTIDY WOUNDS. The problems posed by these wounds arise from three factors they may be large and complicated tissues may have been lost or totally destroyed it is often impossible to tell which of the remaining tissues will survive and which will

die The final plan of treatment for the individual wound cannot be made until it has been thoroughly cleansed and explored (Fig. 16).

Cleansing is best done by the surgeon himself as it provides a good opportunity for determining the general nature and extent of treatment required. The size, number and complexity of the wounds can be noted and the patient and towels can be arranged at the beginning to give most convenient access to wounds and donor areas for any necessary grafts.

The essential purpose of cleansing is not to kill any bacteria that may be in and around the wound but to wash them away The detergent properties of cetrimide in

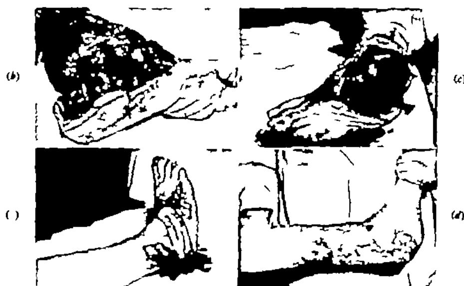


FIG. 16 To illustrate the unreliability of external appearances as guide to the total damage and prospects of repair
(a) Small skin wounds
(b) Severe underlying damage shown in the amputated limb after enlargement of the original wounds
(c) Obvious severe damage but a useful foot was preserved.
(d) Primary split skin grafting.
No other operation required.

1 per cent solution make it useful for removing greasy substances but sterile soap solution does not carry the same (admittedly small) risk of dermatitis and can be used with confidence (Williams and Miles, 1949) Washing should be thorough and fairly vigorous with the vigour applied to the skin and not to the surface of the wound itself With this proviso a soft scrubbing brush is helpful in dealing with horny and grimy skin. The cleansing liquid should be used liberally but should be kept out of the wound, at least during the early stages, by suitably large swabs. The wound itself should be freely irrigated with warm, sterile, saline solution. The need for large and appropriately placed receptacles at this stage will be appreciated.

A tourniquet is often advisable but it should be released after the wound has been fully explored and any evident sources of serious bleeding have been controlled. Otherwise it is easy to fail to recognize ischaemic tissues on the one hand and sources of troublesome oozing on the other

Exploration must be carried out methodically and thoroughly The existing skin wound may be large enough already but should it have to be extended this must be done with due regard to the blood-supply of existing flaps, to the possible need for advancing or re-arranging skin to secure closure or avoid badly placed scars and to the needs of any later operations The full extent of the wound must be carefully traced and examined but until the plan of treatment has been made intact structures should be disturbed and dissected as little as possible

The doubt about the fate of some tissues makes it necessary to lay plans which are flexible enough to be practicable whether the tissues fare well or badly and they should also take into consideration the patient s functional and economic needs. The general policy should be to discard what is clearly dead or irreparable and to retain what is functionally important tissues that will facilitate closure should be retained even though their survival may be in doubt otherwise, doubtful tissues should be discarded It is important to emphasize however that the choice and method of execution of the surgical procedure must pay due regard to the patient s general condition

Muscle that is inert when pinched and which does not bleed should be cut away but bleeding and twitching do not guarantee ultimate survival. Interruption of the main blood supply usually means loss of the limb in large untidy injuries but arterial repair by suture or grafting may be practicable (Rob and others, 1956). Primary suture of nerves should not be carried out but the ends merely approximated if tension permits. Primary suture of tendons, however is sometimes advisable.

Large skin flaps resulting from crushing and shearing injuries rarely survive entire but are often worth while sewing back after the badly damaged or begrimed parts have been cut away This conservative attitude is particularly important when it allows important structures like bones and joints to be covered by skin that has a chance of survival, but if the exposed tissues be suitable for immediate split-skin grafting a more liberal excision of damaged skin may be advantageous. Except with small flaps, healthy looking subcutaneous fat should not be removed as this is time-consuming and may further endanger a poor blood-supply

The sewing back of large areas of damaged skin has been condemned on the grounds that little or none survives and that infection almost always ensues (Prendiville and Lewis 1955). Sloughing, especially of flaps that are dusky and œdematous at the time of operation, is indeed often extensive but with early repair—permitted by prompt resuscitation—infection is by no means the rule. Skin that dies without infection acts as a dressing and the patient remains well and comfortable without fever (Fig. 17). After about 3 weeks the dead tissue is clearly defined and ready to be replaced by skin-grafts.

The combination of swelling of the core of the limb with loss of some skin and retraction and swelling of what remains may make closure by suture difficult or impossible and it is important that flaps that are replaced should be under tension that is as near normal as possible. If fine (00 or 000) sutures placed close to each other and close to its edges enable a wound to be closed completely the tension is not likely to be too great. Another noteworthy consideration is the effect of distortion on a suture line closed at the limit of safe tension. With this in mind the internal fixation of unstable fractures should be looked upon, not askance, but as part of the treatment of the wound as a whole.

When primary closure cannot be achieved by simple suture reliance has to be placed on grafting. Local flaps are often valuable for this purpose (McLaughlin, 1953) but

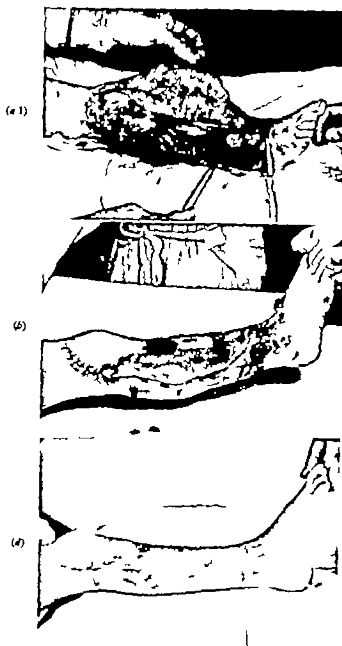


FIG. 17 Typical course of events after replacement of a large skin-flap

(a) 1 and 2. Original injury. Closure by combination of suture and split skin-grafts for a residual gap. Internal fixation of tibia by single screw (a 3)

(b) Three weeks later. No pathogenic organism grown from swab.

(c) Clinical chart.

(d) Healed after excision of slough and grafting.

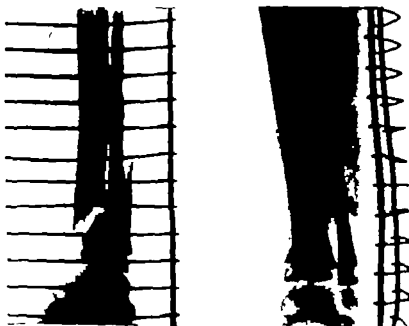


Fig. 17 (a 2)



Fig. 17 (a 3)

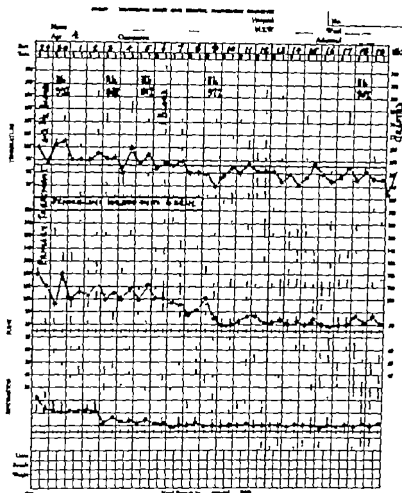


Fig 17 ( )

flaps should not be cut from skin that has been crushed or torn from its fascial moorings If a flap be essential in such circumstances it must be raised from the trunk or another limb but split-skin grafts are applicable in most cases for they will take on almost any living tissue and even span small areas of bare cortical bone cartilage or tendon If the resulting scars prove to be unsatisfactory they can be replaced later by flaps or tubed pedicles (Fig. 18)



FIG. 18. To illustrate the applicability of split skin to cancellous bone and open tarsal joints. The thin grafts were later replaced by skin from a tubed pedicle.

Injuries of comparable severity can occur without breach of the skin though this may later die from the direct effects of the injuring violence aggravated by the effects of subsequent swelling (Fig. 19). To incise such skin for the purposes of internal repair may seem dangerous but as it also allows decompression it may be less hazardous than merely awaiting developments.

Whatever the nature of the wound it is essential to minimize swelling by means of firm, evenly applied pressure supplemented by elevation. Success or failure may depend



FIG. 19. To illustrate extensive, delayed death of skin after a closed injury

upon the care with which the dressing is applied after operation and this should be the responsibility of the surgeon himself.

SPECIAL WOUNDS

The Hands. (Rank and Wakefield, 1953; Reid, 1956). Though the foregoing general principles hold good, the special conditions in the hand may require some modification of emphasis and detail. *The outstanding complications are swelling, infection, and deformity* and of these infection is the most serious. A degree of sepsis which would cause little anxiety in the coarser structure of the arm or leg can permanently disable the closely packed and delicate structures of the hand.

The most difficult decisions are required by the larger and untidy wounds for it is with these that a balance has to be struck between trying to preserve function by retaining tissues of doubtful viability and trying to prevent infection by discarding them The decision has to be made in the light of the importance to the patient s functional and economic needs of the tissues it is hoped to preserve the particular dangers that infection would bring to the particular wound of the patient concerned and the likelihood that the wound has become contaminated by the time of operation Another consideration is the feasibility and ultimate functional efficiency of primary excision and skin grafting. Thus, skin that has been torn from the back of the hand particularly if the flap has a distal base should be replaced by skin grafts at the first operation Provided the recipient area be suitable, split skin provides durable cover here. The special nature of the palmar skin, on the other hand, makes its preservation desirable whenever possible If the palmar fascia or tendons have been exposed by destruction of skin a flap from the trunk or the other arm will be required but provided the subcutaneous fat or paratenon remain and are alive, free grafts of whole skin or thick split skin give satisfactory results. When underlying tendons have been damaged, especially by abrasion, it is often worth while sewing back quite badly damaged flaps and awaiting developments rather than grafting over tendons of doubtful viability Should grafting be unavoidable, however then the use of split skin is preferable to a flap in the first instance split skin is a harmless dressing for dead tendons but dead tendon is an undesirable basis for a flap. The feasibility of applying split skin or a reversed dermis graft (Hynes, 1954) to cancellous bone if necessary after removing the cortex, is worth remembering.

Many untidy wounds include multiple fractures, partial amputation, and serious damage to tendons each hand must be treated on its merits. There is a strong case for internal fixation of unstable fractures for it safeguards suture-lines and may allow movements to be started sooner than would otherwise have been possible. Rings or sutures of wire Kirschner wire, or intramedullary pegs may be used. Primary suture of tendons may be worth while in such cases, not because there is any prospect of restoring movement but for the sake of stabilizing fractures or joints which would otherwise be flail. Some bony injuries are associated with loss of the overlying skin and for these excision of the fracture should be considered because the resulting reduction of bone may allow the skin to be closed by simple suture and preserve a useful though shortened digit (Nemethi, 1955) Fusion of the interphalangeal joints in flexion does not cause much disability but, except in the case of the thumb where only the carpo-metacarpal joint is essential every effort should be made to preserve some movement at the metacarpo-phalangeal joints Pseudarthrosis of the third or fourth is not unsatisfactory provided the adjacent fingers remain to give lateral support but excision of the head of the second or the fifth metacarpal is liable to be followed by lateral subluxation of the finger Prosthetic replacement might be worth considering as a last resort

There are few hard and fast rules governing the indications for and levels of amputation but it is fair to say that the more extensive the damage the more *conservative* the first operation should be When only one finger has been badly damaged immediate amputation may be preferable to a lengthy and disabling plan of treatment which is unlikely to restore a very useful finger but when several fingers have been badly damaged as much as possible of each should be preserved until its eventual value has been assessed The choice between amputation and reconstruction should be based upon this assessment

and upon the patient's needs. As "precision movements" (Napier 1956) are so important an opposable thumb and an opposition post for it should be preserved or restored, whenever possible. Such a post can be built up from a metacarpal by means of a bone graft and a tubed pedicle of skin but its rigidity and lack of sensation make it very liable to injury and the results are commonly disappointing. If the thumb has been lost it can be made good by transferring a finger in preference to constructing a rigid post (Littler 1953). Apart from their functional value, injured fingers can be used as a source of skin which, furthermore, may retain more or less normal innervation. They can be filleted at the first operation and the skin transposed to the hand or an



FIG. 20. To illustrate transposition of skin from a filleted finger

adjacent digit or they may be worth preserving in the first instance with an eye to using their skin to replace unsatisfactory scars later (Fig. 20).

As a general rule, as much as possible of an innervated and controllable digit, and especially the thumb, should be retained because a "power grip" (Napier 1956) requires the ability to bring the fingers strongly towards the palm. The fifth metacarpal and its digit contribute appreciably to the grip and should not be amputated without good reason. A short length of proximal phalanx does not play much part in grasping but it does help to prevent small objects from slipping out of the palm. Disarticulation at the metacarpophalangeal joint leaves a broader and stronger hand than does amputation through the metacarpal and is usually the more satisfactory procedure. It is a matter of individual taste which hand looks the less ugly.

With all open wounds of the hand sound closure is very important and as far as possible suture-lines should be so arranged as to avoid subsequent webbing. When grafts have to be used it is preferable to have their edges off tension lines and it is justifiable to remove some normal skin to allow this. There need be no hesitation in carrying out primary Z-plasty if healing can be relied upon but the skin of the hand does not lend

itself to rotation, transposition and advancement. Thenar and cross-finger flaps are useful for the closure of small defects on the tips and shafts of the digits (Horn 1951, Barclay 1955) but they carry the risk of disabling an hitherto normal structure and should not be used if simpler measures will suffice.

Penetrating Wounds. Few breaches of the skin are so trivial that the possibility of deep penetration can be discounted on sight. When only tendons, nerves, and main vessels are at risk clinical examination will usually make it clear whether they have been



FIG. 21. This patient had two or three trivial looking scalp wounds from a blow with the broken end of a bottle. A large frontal skin-flap was turned down. The depressed fragment had torn one of the cerebral veins very near the sagittal sinus and severe bleeding occurred during operation. Four bottles of blood given.

injured or not, but if there be any doubt or if the cavities of joints or the cœlom be at risk, the wound should be explored as a formal surgical procedure. A probe is an unreliable guide to the extent of a wound, which should be determined by sight and not by touch. though there may be no important damage, foreign material may be lodged deep in the wound. Wounds of the abdominal wall, chest, and buttocks need especial care and in the last instance endoscopy may be advisable.

Penetrating Chest Wounds. When open or valvular these should be sealed with a suitable dressing pending formal closure and the pleural space allowed to empty through an intercostal water-sealed tube. If primary thoracotomy be not indicated a careful watch must be kept for evidence of cardiac tamponade, perforation of the gullet, bronchial fistula, mediastinal hæmatoma, and pleural effusions of all kinds.

Scalp Wounds and Scalping. Trivial looking punctures require more than a cursory glance or perfunctory suture for they may overlie depressed fractures (Fig. 21) and penetrating wounds of the brain.

Unless completely separated the scalp should be replaced at once to facilitate the circulation and sewn back as soon as possible thereafter The hair should be cut short. Complete avulsion of the scalp calls for split-skin grafting at the outset. Rotation flaps can be used later to help reduce the cosmetic disability but the mental anguish of these patients is not easily overcome if large bald areas remain.

Injuries of the Face. These require a particularly delicate technique and as the tissues can ill be spared any necessary trimming must be as conservative as possible Wounds should be closed in layers to prevent the muscles from retracting and causing mobile, depressed scars and asymmetrical facial movements. The first skin stitches should be placed at key points such as the edges of the lids and the red margins of the lips. Bone and cartilage should be covered and for the jaw this may require the use of flaps from the neck. The exposed cartilage of the ear may be buried in the scalp while more distant skin is being brought up to it but occasionally a flap can be advanced from the cranial surface to cover the rim of the ear and the new defect made good with split skin. When penetrating wounds of the mouth cannot be closed by suture in layers, mucous membrane and skin should be sewn together and if there has also been loss of bone the jaw will usually need to be splinted. It is at the same time justifiable to nibble away enough bone to enable the soft parts to be closed over it. Much the same holds good for the nose. Wounds of the masseteric area should be explored with the facial nerve and the parotid gland and its duct in mind. The duct should be repaired over a splint of nylon or other thread and wounds of the gland require suture of the capsule Injuries of the salivary apparatus should not be drained lest a fistula be encouraged. An extra-glandular collec tion of saliva sometimes forms but it may respond to aspiration on a few occasions.

Loss of buccal mucosa should be made good by thin split-skin grafts cut from an almost hairless site such as the inner side of the arm and kept in place by a mould of gutta percha or stent. Any such mould should maintain at least the normal depth of the sulcus that is being treated.

Injuries of the Jaw The airway may be seriously endangered by bleeding and by the prolapse of the tongue or soft palate into the pharynx. Unconsciousness may further complicate the situation. When possible the patient should lie prone or semiprone with the head low otherwise the tongue must be held forwards by an oral airway a clip, or a stitch. Tracheal intubation and tracheotomy may be required and are of special value, when there is a head injury They should not be looked upon as last resorts but used deliberately to maintain rather than desperately to restore a clear airway

Though injuries of the jaws, nasal skeleton, and zygoma commonly accompany wounds of the face and should always be looked for their management will not be further considered here, nor will those affecting the eyes (but *see* Volume II pages 82 and 209).

Bites. These are often untidy wounds which carry a high incidence of infection (human bites particularly) but many are no more than abrasions with contusion. If suture be carried out it should be with the realization that the wound may break down and have to be re-opened. Antitetanus serum should be given and prophylatic administration of one of the wide-range antibiotics is advisable. The progress of the wound should be watched closely

Gravel Rash. Scrubbing is a rough and often ineffective way of removing ingrained dirt. Better results are obtainable by a combination of patience a good light, and plenty of sharp-pointed scalpel blades with which to tease out the individual particles without

injuring remaining epithelium Though such a wound may look septic a few days later this appearance may be due to a multitude of tiny sloughs and not to infection at all. If penicillin cream be granted a place in the treatment of wounds (Jackson and others, 1951 Lowbury and others, 1952) it is useful here for it helps sloughs to separate and reduces the risk of streptococcal infection but if the abrasion be very deep, split skin can be applied to it with the alternative objects of acting either as a dressing or as a graft according to whether epithelial loss has been partial or total

According to their depth and extent, discoloured scars should be treated by excision and suture, excision and grafting, or by abrasion by means of sand paper a wire brush, or dental burr

Control of Infection

There is at the present time a tendency to equate the control of infection with the prophylactic and therapeutic use of antibacterial drugs this has resulted in the wasteful and harmful use of powerful but two-edged weapons. Such undesirable clinical effects as anaphylaxis and urticaria are obvious and not readily forgotten but effects upon bacterial sensitivity being unseen, make less impact and do not always influence as much as they should the decision to use or withhold these drugs in the individual case (Lowbury 1955 Rees and others, 1955).

Provided they are treated by prompt and effective surgery most tidy wounds and many of the smaller untidy wounds that can be made tidy heal by first intention without the use of antibacterial drugs. The key to success is the exclusion of organisms for it has been shown that most of the smaller wounds of peace-time are not contaminated at the time they are inflicted but later on, from the patient's own skin (Williams and Miles, 1949), by direct contact or from the air The risk of adding organisms to a wound must be reduced by providing an effective cover of sterile dressings as soon as possible and by avoiding detailed examination of the wound until it can be exposed in suitable surroundings. Unfortunately many theatres are sources of infection (Girdlestone and others, 1951 Colebrook, 1955 Blowers and others, 1955 Hare and Thomas, 1956) and the patient with large wounds is in special danger now that advances in resuscitation and anæsthesia have made possible prolonged operations (and, consequently prolonged exposure of wounds) within a few hours of injury The ideal of a supply of sterile air to all operating theatres and dressing rooms is still a long way off and in the meantime every effort must be made to avoid taking contaminated materials such as clothing and soiled dressings into operating theatres and to reduce as far as possible the activity and movement which are inseparable from surgical preparations.

Antibacterial drugs should not be used "just to be on the safe side" but because there is a serious likelihood of infection Wounds which are likely to have been contaminated up to the time of closure wounds in which clot or tissue of doubtful viability remain wounds in which infection, though unlikely would be disastrous and wounds in persons with an existing septic focus require the use of such drugs.

A fuller discussion of this subject and considerations governing the use of anti-tetanus and anti-gas gangrene serum will be found in Chapter 3 but it seems likely that whatever drugs and sera may be available the best defence against infection will remain surgical, with its object of bringing viable tissues together throughout the whole extent of the wound, in clean air and as soon as possible after injury

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CHAPTER III

INFECTED WOUNDS

E. J. L. LOWBURY AND RUSCOE CLARKE

Introduction. Wound infection can be considered in terms of causative bacterial agents and of conditions which predispose to the development of clinical sepsis. The problem involves both the seed and the soil.

Most wound infections produce local and general changes which vary in severity but are not peculiar to the infecting organism. It is often possible, however, to recognize with reasonable certainty acute infections due to *Streptococcus pyogenes*. *Pseudomonas pyocyanea* will usually show its presence by a blue-green pigmentation of dressings. A few species of bacteria growing in wounds give rise to characteristic clinical syndromes, such as tetanus and gas gangrene.

Certain descriptive terms require definition. *Contamination* means the transfer of bacteria to a wound, or the presence of bacteria in it; the growth of bacteria in a wound is described as *colonization*. *Sepsis* describes the clinical changes which occur in a wound through bacterial colonization. The word *infection* is used to mean either the injurious effects caused by bacteria or the transmission of disease due to such bacteria, the sense being usually obvious from the context. *Invasion* describes the process whereby contamination leads to clinical infection. *Silent infection* is infection (in the first sense) without manifest sepsis, shown by its adverse effects on healing or by the subsequent development of frank clinical infection. *Cross infection* means the transfer of infection from one patient to another; it is one form of *added infection*, which includes the results of contamination by bacteria from the patient's own nasal or intestinal flora. The last terms (and even the word "infection") are often applied, especially by bacteriologists, to the movements of organisms without reference to the actual incidence of disease. It would then, perhaps, be better to speak of contamination, but that term is generally used in a more restricted sense to indicate flora present in a wound before they begin to multiply—roughly for the first 8 hours.

Ætiology

PREDISPOSING CAUSES. Any open wound can become infected by direct contamination. A closed (or apparently closed) wound of deep tissues may become infected through the blood stream or through damaged skin. The factors which determine the occurrence and severity of wound infection may be classified as follows:

(1) *The Presence of Pathogenic Bacteria.* The likelihood of infection depends in the first place on the numbers and virulence of bacteria which gain access to the wound at any time until healing is completed; hence the risks of tetanus and gas gangrene in wounds contaminated with soil and fæces, and the risks of added infection with antibiotic resistant staphylococci and other organisms in hospital.[14, 19] There is a greater risk of wound infection if the patient has a septic lesion elsewhere at the time of the injury.

(2) *The Nature of the Initial Injury* The risk of infection depends not only on the presence of contaminating organisms, but also on the method by which they are introduced. For example, deep penetrating wounds are liable to be infected through contamination at the time of injury by contrast, burns are virtually sterile at first, but specially prone to added infection.

(3) *The Extent and Depth of the Wound* The bigger the wound, and the longer it remains open or unhealed, the more likely it is to acquire contaminating organisms.

(4) *The Nature and Extent of the Damaged Tissues* Living tissues with a normal blood supply show considerable resistance to infection. Damaged tissue, on the other hand, may become a favourable medium for bacterial growth. The danger is greatest when muscle is devitalized, as gas gangrene may arise in such a lesion. Adipose tissues are very prone to infection when damaged or contaminated. Joint capsules, bones, ligaments, tendons and fascia readily become infected when bathed in pus, and such infection often has severe consequences It is, however unlikely (though often assumed) that any of these tissues has exceptionally poor resistance on exposure to sparse contaminants.

(5) *Retained Foreign Bodies* These increase the risks of infection because of the bacteria which they carry and the tissue damage they produce. Wood splinters are very liable to cause sepsis, which may be latent. The risk from clean metallic foreign bodies has probably been exaggerated, as the presence of metal does not, as a rule, in itself predispose to infection.

(6) *The Presence of Blood Clot in the Tissues* Many organisms grow readily in blood clot. Serious wound infections often start in a hæmatoma which may be clinically undetectable.

(7) *Tension in the Depths of the Wound.* The development of tension in the depths of the wound is probably the most serious of the factors contributing to the establishment of dangerous infection. It can result from hæmorrhage, from obstruction to venous return, and from œdema associated with the reaction to trauma or the onset of infection. This danger is particularly acute in penetrating wounds and when the skin is closed after inadequate treatment of an underlying injury

(8) *The Anatomical Site* The risk of infection is influenced to a large extent by the adequacy of blood supply For example, the tissues of the face and scalp, which have an excellent blood supply generally heal well and are more resistant to infection than certain other regions (e.g., the front of the leg) where the blood supply is often inadequate.

(9) *Movement* In the presence of other factors pre-disposing to infection, movement of the injured part may be an important contributory factor

(10) *The General Resistance of the Patient* Resistance to infection is reduced in diabetes mellitus, chronic nephritis, anæmia, avitaminoses, agammaglobulinæmia, and also in patients whose nutritional state is poor or who are receiving treatment with corticosteroids.

(11) *Treatment* The occurrence severity and nature of wound infection is greatly influenced by the form of treatment.

ORGANISMS CAUSING WOUND INFECTION. *Streptococcus pyogenes* (the hæmolytic streptococcus of Lancefield s group A), *Staphylococcus aureus* (the coagulase-producing staphylococcus) and various species of coliform bacilli are the organisms most commonly

described as agents of wound infection. Of these, *Strep pyogenes* is liable to cause the severest and most acute effects It was the predominant cause of wound infection in hospitals before the introduction of the sulphonamides and penicillin [17, 18] The pre dominant wound pathogen to-day is *Staph aureus* It has proved less vulnerable to chemotherapy partly because of its prevalence in the nose and on the skin, and partly because of the readiness with which drug-resistant forms emerge.

Many bacterial species can be isolated from infected wounds, often in mixed culture, particularly when healing has been delayed and necrotic tissues remain Most of these can also be found on healthy skin or in the respiratory or alimentary tracts. They include micrococci (e g. *Staphylococcus albus*), diphtheroid bacilli α hæmolytic and non-hæmolytic streptococci, anærobic cocci coliform bacilli members of the Proteus group clostridia (particularly *Cl welchii*), Gram-negative cocci and yeasts. Aerobic spore bearing bacilli may sometimes be found in large numbers in a wound, but are usually replaced by other organisms. Before diphtheria became a rarity wound infection with *Corynebacterium diphtheriæ* was sometimes encountered. *Pasteurella septica* has been found as the predominant organism in infected dog or cat bites. *Erysipelothrix rhusiopathiæ* causes a specific infection (erysipeloid) in meat handlers. Species of Bacteroides are often isolated from foul smelling necrotic wounds, usually in association with other ærobic or anærobic organisms. One should include *Bacillus anthracis* in this list, though the malignant pustule of anthrax generally follows insignificant abrasions of the skin.

Wounds in different parts of the body tend to have characteristic flora e.g. coliform bacilli are commoner on buttocks and thighs, staphylococci on hands and feet. In large wounds which are allowed to remain open and in burns a different flora often appears at later stages after injury e.g. fæcal organisms, including clostridia, which are often abundant during the first few days, are usually replaced later by pyogenic cocci *Staph. aureus* is often found pure or predominant on granulating surfaces coliform bacilli, *Ps. pyocyanea* and Proteus often predominate on moist slough.

Pathology Wound infection is a complication of an existing lesion. The injury itself may cause inflammation and necrosis, and it is often difficult to distinguish the effects of the original trauma from those due to bacteria.

The pathological changes caused by bacteria in wounds consist, as elsewhere, of a mixture of degeneration and inflammation. The details vary somewhat with the type of organism e g. *Strep pyogenes* may cause an invasive lesion characterized by cellulitis and erysipelas, sometimes followed by diffuse gangrene and septicæmia. The invasiveness of *Strep pyogenes* is probably due, at least in part, to its production of an enzyme streptokinase, which releases a powerful fibrinolysin from an inert precursor in the plasma. This destroys or prevents the formation of a fibrin barrier around the area of infection. *Staph. aureus* by contrast, releases little fibrinolysin but produces coagulase an enzyme which causes the precipitation of fibrin from fibrinogen staphylococcal infections tend to be circumscribed by a fibrin barrier which protects the host from invasion, but also protects the parasite from antibodies, antibiotics, and phagocytes.

Both *Staph. aureus* and *Strep pyogenes* produce exotoxins which destroy leucocytes and cause necrosis of tissues, and both stimulate neutrophil leucocytosis pus tends to be formed at the site of infection, and the organisms are therefore called "pyogenic" Coliform bacilli and *Ps. procyanea* act as pyogenic organisms in the urinary tract, and

they appear to cause a similar infection in wounds. Delayed healing and failure of skin grafts may occur when these organisms (especially *Strep pyogenes*) colonize burns.[20]

Wound infection may spread through the connective tissues, causing cellulitis through the lymph channels, causing lymphangitis and lymphadenitis or through the blood stream, as septicæmia or pyæmia. The spread of an infection is not necessarily related to the size of the wound or the severity of the local reaction e.g. fatal septicæmia may follow a pinprick at autopsy or operation on a case of streptococcal disease. In pyæmia, septic emboli from a suppurating lesion lodge in the viscera or other tissues, causing secondary abscesses. The term "toxæmia" is primarily clinical in usage, as no toxins can be satisfactorily demonstrated in the blood of "toxæmic" patients their existence is suggested by the presence of cloudy swelling and fatty degeneration in the viscera of severely infected patients even when blood cultures are negative. Some of the changes primarily attributed to toxins may be due to metabolic disturbances associated with the "illness of trauma."[21]

It is often possible to differentiate between two stages in the development of wound infection first, a stage of spreading infection during which the patient may be ill and surgery ill-advised, and a later stage of localization associated with the formation of pus. With the help of antibiotics, supported when necessary by blood transfusion and other forms of replacement therapy patients can usually be kept in good condition and wound infections become localized within a short time of onset at this stage, infection tends either to heal by itself or to benefit from surgical intervention.

Clinical Features. The diagnosis of wound infection should depend on clinical observations supported whenever possible by bacteriological findings. It is customary to regard wounds left untreated for 12–24 hours as potentially infected. This practice is justified as a guide to treatment, although under certain conditions the time may be extended, particularly when systemic antibiotics have been used. Clinical infection is frequently not apparent even in wounds seen as late as 36–48 hours after injury

The clinical features of an infected wound vary with the nature of the wound. When there is adequate drainage, wound infection is characterized by pain, redness of the skin margins and the appearance of an exudate which is at first serous but becomes purulent. Of the four classical signs of inflammation, heat is likely to be missed all the signs, however may be present over a hæmatoma, even when there is no apparent infection. When drainage is inadequate, redness, swelling, œdema and evidence of cellulitis may appear rapidly

Cellulitis is recognized by spread of the inflammation to tissue adjoining the wound. The skin over it is red, shiny tense, and tender and there is no sharp margin to the inflammation. The patient may be ill with pyrexia, rigors, rapid pulse, apathy or irritability anorexia, nausea and vomiting, and oliguria. In lymphangitis the superficial lymphatics which drain the infected area can be seen as thin red lines lymphadenitis produces swelling and tenderness of the regional lymph glands. In erysipelas, which may occur in streptococcal wound infections but is now a rarity there is a raised, indurated, irregular area of red tender skin with a sharp margin which advances, sometimes with bullæ on the inflamed surface, and in severe cases with constitutional symptoms as in cellulitis. Streptococcal infection may lead to extensive gangrene, characterized by irregular purple patches appearing in the red inflamed areas of cellulitis on the third and fourth day of the infection. The purple areas become anæsthetic, and blisters appear on

them. The patient is usually apathetic, with moderate fever and a rapid pulse. Brewer and Meleney[7] have described a progressive gangrene at the site of abdominal operations associated with "synergistic" infection by a microaerophilic non-hæmolytic streptococcus and *Staph. aureus* They regard this infection, which is rare, as a specific clinical entity

Septicæmia may accompany any of these local extensions of wound sepsis without additional signs. It is characterized, as a rule, by pyrexia or hyperpyrexia, raised pulse and respiration rate, rigors, sweats, exhaustion, and purpuric or erythematous eruptions. The spleen may be palpable, and there may be a hæmolytic anæmia Leucocytosis is usual. Diagnosis depends on the finding of a positive blood culture in a patient with these signs and symptoms. Established pyæmia may be characterized by an intermittent fever in addition to evidence of septic emboli

Wound infection can be modified by chemotherapy When this is used as prophylaxis, infection may be aborted, or may present during the first few days with minor redness of the skin margins and a transient moist exudate. In deep wounds, chemotherapy may conceal the development of a deep infection for some days, even when its presence may be suspected from the appearance of the temperature chart.

Prophylaxis. Prophylaxis of wounds against infection involves (*a*) *exclusion of bacteria* by the use of aseptic methods at operations, at dressings, and during the inspection of wounds, and by measures to prevent added infection in the wards (*b*) *promotion of the natural defences* by removal of dead tissue, blood clot, foreign bodies, etc. and by preservation of the viability and the blood supply of tissues, e g. by division of deep fascial envelopes and through gentle handling, rest (including splintage) and the avoidance of tight sutures (*c*) in certain cases, *systemic or local chemotherapy* These principles must be applied concurrently since none of them contributes more than a partial defence against bacteria.

Aseptic surgery was developed by A. von Bergmann, Schimmelbusch, Halsted, von Mikulicz Radecki and others, and it gradually replaced the antiseptic methods by which Lister and his followers had eradicated hospital gangrene. Its aim is to prevent the access of bacteria to surgical wounds by eliminating reservoirs and vectors of infection and by blocking the channels of transfer To achieve these ends an elaborate discipline has been evolved, the principal components being the use of sterilized instruments, towels and other equipment, the avoidance of unnecessary exposure of wounds, and the attempt to screen off or destroy bacteria carried, especially on the skin, by the patient and the surgical team. (For details of the aseptic discipline *see* Walter 1948 [23])

Some of the methods are admittedly imperfect (e.g. skin disinfection) and research is needed for appraisal of current practice and for improvements Certain principles have until recently been neglected e g. the importance of providing clean conditioned air in operating theatres,[24, 25] and the necessity for extending a rigorous aseptic discipline to the dressing of surgical and accidental wounds[26, 14] and to the management of burns.[27] The measures against added infection in wards—cubicle and bed isolation, dust suppression, adequate cover of wounds, etc.—must be considered as a part of the same prophylactic scheme.

Clean operation wounds and *small cuts and abrasions* will normally heal well under a dry sterile dressing, and need no chemotherapy There is evidence, in fact, that the use of a routine chemotherapeutic "umbrella" may lead not only to the emergence of

resistant organisms, but also to a greater incidence of post-operative sepsis.[19, 22] The indications for prophylactic chemotherapy are discussed in Volume 3 *Chapter 15* Small open wounds should first be cleansed with soap and water or a detergent antiseptic (e.g. 1 per cent cetrimide solution) The dressing should ideally allow evaporation of moisture without allowing bacteria to gain access from the outer surface these conditions have been provided in certain plastic adhesive dressings (e.g. nylon and "Porvic") Some surgeons have favoured the use of a transparent film of acrylic resin ("Nobecutane") sprayed in a volatile solvent others have recommended the avoidance of any dressings in certain operation wounds.

More extensive wounds require additional measures which will vary with the site, nature, and extent of the injury and will usually involve cleansing and surgical treatment under anæsthesia. The wound and the surrounding skin should be cleansed with a detergent (e.g. soap and water or 1 per cent cetrimide) the purpose of this cleansing is to remove dirt rather than to achieve sterility Some surgeons prefer to use sterile physiological saline for the deeper tissues. The wound must be fully explored, foreign bodies and dirt removed, and non viable tissue excised. The viable tissues which remain have considerable powers of resistance to infection and may sterilize themselves, especially if they can be gently apposed by sutures and bandaging, or grafted in areas where skin is missing.

Under war conditions when evacuation is necessary wound exploration inadequate, or facilities for careful observation absent, wounds should be left open, and closed as a second stage operation (delayed primary suture). In civilian injuries this should rarely be necessary unless definitive surgery is contra-indicated by the general condition of the patient.

In the presence of severe contamination, systemic chemotherapy should be given, together with appropriate measures against tetanus (*see* below) The most important measure in the prevention of gas gangrene is the radical removal of devitalized muscle The earlier the treatment, the more likely it is to result in primary healing With the aid of prophylactic chemotherapy it is possible to carry out full primary surgical toilet and closure or grafting 24 hours or in some circumstances and regions, even 48 hours from the time of injury If treatment has been much delayed, however it may be necessary to leave the wound open and carry out repair as a deliberate second stage of treatment Penetrating wounds, particularly those of fingers, hands and feet, carry the risk of deep infection, but full exploration may be difficult. They should be treated by rest, elevation, chemotherapy and measures to prevent tetanus Exploration may be indicated in the presence of a large foreign body or likelihood of joint damage

Opinions vary on the use of chemotherapeutic agents and antiseptics applied locally to wounds. Wright[14] and Fleming[18, 19] showed that leucocytes were killed and bacterial growth in blood was promoted by various antiseptics. These *in vitro* tests, however were felt by Garrod[20] to exaggerate the case against local chemoprophylaxis In his opinion infection of open wounds may be prevented by local application of acridines, provided that treatment is started within a few hours. Locally applied penicillin mixed as powder with sulphonamides[21, 22] was considered by some during the Second World War to have prophylactic and therapeutic value in wounds, and the prophylaxis of burns by penicillin, polymyxin and other locally applied agents has been demonstrated in controlled trials (e.g. [22, 21]). As many wounds become infected even with the strictest

asepsis, there is some rationale for the use of local chemoprophylaxis in severely lacerated and contaminated wounds. In view of the resistance of many bacteria to most of the agents available and the risks of sensitization, it is probably better to use a mixture of agents rarely or never administered by systemic routes and unlikely to induce the emergence of resistant organisms (e.g. neomycin, bacitracin and polymyxin B). Their value in the prophylaxis of lacerated wounds, however has still to be assessed. Many clinicians doubt the value of local antibiotics in the treatment of wounds at the acute stage

Treatment. The details of wound treatment must be modified in the presence of established infection. It may be necessary to remove stitches or even to open up the whole wound, particularly where there is evidence of an infected hæmatoma or pus under tension. In the past, incisions for the insertion of drains have been used in the treatment of such conditions, but this may lead to secondary infection from the outside as a result, sinuses become established and further surgery is required. It is usually preferable to leave the wound wide open, with tulle gras separating opposed surfaces the wound should be firmly bandaged and splinted if necessary The infection may often be controlled in a short time with the aid of chemotherapy and the wound can then be re-sutured or the surfaces grafted as a delayed procedure. Even when drainage tubes are considered undesirable, there may be a case for the introduction of fine tubes through which chemotherapeutic solutions can be instilled into the wound

If infection is severe, it may be necessary to explore the wound, and when possible remove necrotic tissue. Many clinicians still favour the use of hypertonic saline or sodium sulphate dressings to encourage the passage of fluid outwards through the tissues. Others prefer irrigation with eusol or other antiseptic solutions, though it is probable that any benefits derived from this treatment are due to the fragmentation and removal of slough. Since the advent of chemotherapy and the appreciation of the importance of excision of necrotic tissue and early wound closure, many surgeons have discouraged the use of local antiseptics.

Once the acute stage of wound infection has been brought under control, the modern tendency is to rely on surgery to secure early wound healing. There may be circumstances in which wounds benefit from closed plaster treatment, but it is now clear that the ill effects of accumulating discharges make any such treatment inferior to excision of necrotic tissue followed by suture or grafting. Secondary suture or grafting is also the most effective treatment for granulating areas in wounds which have failed to heal Such areas become infected sooner or later but clinical experience has shown that skin grafts applied as dressings often "take" in spite of the presence of bacteria, and help to clean the wound even if they do not take completely

Any infected wound that is not trivial benefits from immobilization. In wounds of the upper limb a sling may be sufficient, but wounds of the lower limb and trunk may require bed rest. Immobilization with plaster or other forms of splintage may be desirable for infection of severe or extensive wounds. Elevation of injured extremities is often a valuable addition to rest or splintage. Septic wounds must be adequately covered with protective dressings, which must always be changed as soon as they become soaked with exudate.

Chemotherapy is unnecessary for trivial infections of small wounds In severer infections it should be used as an adjunct to the local measures described above The *selection of agents should be decided*—or modified—in accordance with the results of

sensitivity tests on the wound flora. If a pure culture of *Streptococcus pyogenes* is isolated from a wound, penicillin (by injection) is the antibiotic of choice It is common, however to find a mixed flora, and if this includes a penicillinase-producer even the sensitive organisms in the mixture are unlikely to respond to penicillin therapy For such infections the tetracyclines and erythromycin have been found effective. For tetracycline-resistant staphylococci, which are commonly found in hospital infections, erythromycin and novobiocin are the drugs of choice, but they should be reserved strictly for infections which require treatment and against which other agents are in active, on account of the readiness with which resistant staphylococci emerge. A selected mixture of agents is often desirable (e.g. novobiocin and erythromycin, or penicillin and streptomycin). The rationale of selection is discussed in Volume 3 Chapter 15 With the exception of *Strep pyogenes* bacteria are liable to persist in wounds during systemic chemotherapy even when they are sensitive to the agents administered their spread to the blood stream and to other organs, however is undoubtedly hindered by the treatment.

Local chemotherapy is admittedly less likely to succeed in its object than local chemoprophylaxis[30] the indications for its use, however are less disputed, since it is obvious that higher concentrations of antibiotics can be applied directly to a wound than will reach it through the blood stream after oral or parenteral administration. Good results may be expected if the drug can reach all parts of the wound, and therapeutic effects of penicillin and of chloramphenicol against *Strep pyogenes* and of poly myxin against *Ps pyocyanea* have been shown after local application of these antibiotics to burns. Abscess cavities may also in some cases, be effectively treated by instilling a solution of the agent. Unless the infecting organism is known, a wide spectrum antibiotic (e.g. 5 per cent chloramphenicol in propylene glycol[29]) or a mixture of anti biotics (e g. bacitracin, neomycin and polymyxin B) should be used. Meleney[7] has recommended the application of an aqueous suspension of zinc peroxide for the treat ment and prophylaxis of infection in deep wounds, and considers it to be particularly effective against clostridia and anerobic streptococci in addition to killing bacteria, it is claimed to destroy clostridial toxins and to have deodorant properties. A combination of local and systemic chemotherapy is undoubtedly more effective than either used alone both should be given in severe infections, but even this procedure will only cause the expulsion of certain pathogens from a proportion of infected wounds.

The systemic effects of wound infection have been greatly reduced by the advent of blood transfusion and the antibiotics. Pyrexia will generally respond to a combination of local surgery and suitable chemotherapy In the absence of specific effects from visceral injuries, early fluid and solid intake should prevent the development of any nutritional or metabolic disturbance. Even when severe infected wounds have been neglected, the general state of the patient can be rapidly improved by repeated transfusion of stored blood or packed cells sufficient to restore and maintain a normal hæmoglobin and blood volume. This will usually lead to a restoration of appetite and so facilitate the ingestion of an adequate high vitamin, high protein diet. The clinical picture of chronic suppura tion leading eventually to gross nutritional deficiency extensive decubitus ulceration and amyloid degeneration is to-day largely preventable

Chronic wound infection is commonly associated with sinuses from foreign bodies, bone involvement or scar tissue strangling the blood supply to neighbouring tissues. It sometimes results from failure [illegible] healing associated with vascular disease It is

occasionally due to tuberculosis, syphilis or actinomycosis. Chronic ulcerations are likely to remain infected so long as they are unhealed

Surgical correction of the local causes followed by suture or skin replacement is often the most satisfactory form of treatment (except for specific infections) Occasionally there can be major problems requiring a combined orthopædic and plastic approach. In the lower limb in particular amputation may sometimes be the only quick road to healing. Chemotherapy for chronic infection by pyogenic organisms is often ineffective because the organisms are commonly resistant to antibiotics given by systemic routes and imperfectly accessible to agents which can be applied locally

Under such conditions access to chemotherapy is frequently one of the objectives of surgery Local application of streptokinase and streptodornase may be beneficial for the removal of sloughs when these are present.

Gas Gangrene

Gas gangrene is an infection of devitalized muscle by certain spore-forming anærobes, with absence of inflammatory reaction in the infected muscle and with severe "toxæmia," circulatory failure and hæmolytic anæmia.

Ætiology Gas gangrene is liable to occur in deep penetrating or lacerated wounds, especially in muscle damaged or deprived of its blood supply and when foreign bodies —especially soil, calcium salts, road dirt or soiled clothing—are introduced. Inadequate primary surgery after wounding is an important predisposing factor The disease occurs most commonly after battle injuries, especially those involving muscle, and occasionally in civilian life after street injuries, especially in open fracture

The commonest organism found in the lesions of gas gangrene is *Clostridium welchii* which is usually present with other anærobic and ærobic species the latter probably improve the conditions for the growth of anærobes. *Cl welchii Cl septicum* and *Cl œdematiens* are considered capable of initiating the disease, but the symptoms of gas gangrene are undoubtedly aggravated by other clostridia, especially *Cl. histolyticum* which is strongly proteolytic Clostridia of gas gangrene can be isolated from the fæces and from the skin of many normal subjects, and are common in soil, dust, and air They are often found in apparently uninfected wounds. In connective tissue they may cause *benign anærobic cellulitis* a condition associated with gas formation but no toxæmia.[34]

Pathology[33] The affected muscles appear dull brick red, becoming green and eventually black they have a soft friable consistency Gas bubbles are seen inside the sheath in infection with *Cl welchii* with *Cl œdematiens* there is more œdema and less gas. Infection spreads rapidly along the muscle, and also through perforations in the sheath to adjoining muscles. On microscopic examination, the muscle is seen to be necrotic, with a loss of striations and of nuclei. The fibres are fragmented and separated from the sheath by exudate. Large numbers of Gram positive bacilli, often accompanied by other bacterial forms, can be seen in sections and in films of the exudate. The muscle and exudate show little if any cellular reaction. The solid viscera show fatty degeneration, and many organs (especially the liver) may be honeycombed with pockets of gas due to terminal *Cl welchii* septicæmia.

Growth of the clostridia is favoured by a low oxidation-reduction potential and by an acid reaction, both of which are found in injured muscle Toxins produced there

include lecithinase and collagenase, which damage the neighbouring uninjured muscle and render it capable of supporting the growth of clostridia, and hyaluronidase which facilitates the spread of the infection.

Clinical Features. The incubation period may occasionally be as short as 4 hours, but usually signs appear 24–48 hours after injury A longer incubation period may be associated with a heavy growth of aerobic organisms which prepare the ground for the anaerobes

The patient may complain of pain in the wound and show increasing evidence of systemic illness—a pale, haggard face, brown furred tongue, vomiting, agitation, delirium, stupor pyrexia (104–105°F), rigors a rapid feeble pulse (120–150) and a low blood pressure. The wound may be swollen and tense, with pale everted edges from which oozes a serous or blood-stained discharge. The neighbouring skin is dusky and mottled, and crepitant on palpation bubbles of gas can be squeezed from the wound on gentle pressure, and can be detected by X-ray examination before they are apparent to the eye or the touch. The subcutaneous tissue appears grey and necrotic, and the muscles are swollen and emphysematous There is a characteristic odour variously described as "sweet," "acrid," or "mousy" Severe hæmolytic anæmia is commonly found. In the severest cases there is a subnormal temperature, and the patient passes rapidly into coma and dies. A fatal outcome is usual in gas gangrene unless treatment is started promptly

Some observers have considered that the early picture of gas gangrene has been altered by chemoprophylaxis, so that diagnosis at this stage can only be made from inspection of the wound, rather than from the presence of severe pain the anxious facies, and a low blood pressure.

Differential Diagnosis. Cellulitis and gangrene due to *Strep pyogenes* may be similar in its clinical presentation, but no gas is formed, and the exudate shows streptococci and neutrophilic leucocytes. In *benign anaerobic cellulitis* there is gas formation but no muscle involvement or toxæmia. In *anaerobic streptococcal cellulitis* gas is also formed, but the onset is insidious, and streptococci are found in the exudate. *Surgical emphysema* may follow injury to the air passages or entry of air from the outside through a peripheral wound It is detected by crepitus on palpation, without the other local signs that characterize gas gangrene Severe gas gangrene may present a clinical picture which is indistinguishable from *oligæmic shock* It may be difficult to make the distinction except at operation.

Prophylaxis and Treatment. The most important measure in the prevention of gas gangrene is prompt and adequate surgery[37, 38, 39, 40] There is more uncertainty as to the prophylactic value of antitoxins and chemotherapy Both have been found useful in the protection of animals against experimental gas gangrene, chemotherapy appearing to be more effective by local application than by systemic administration, and better in combination with antitoxin than alone.[35] The conditions of warfare precluded a statistical evaluation of these methods in the campaigns of 1939–1945 the value of penicillin was strongly suggested by the lower incidence and mortality rate from gas gangrene in troops in North West Europe after the drug became more freely available (in 1944 and 1945), though not in prisoners of war (who were treated with sulphonamides only).[31] An analysis of records during the Italian campaign revealed that prophylactic serum had no effect on mortality penicillin, on the other hand, appeared to have great value[39] In Korea (Howard and Inui, 1956) there was no mortality in

4,900 casualties from gas gangrene in spite of clostridial contamination. This was due to rapid evacuation, blood transfusion and antibiotics. Antitoxins were not used for prevention or treatment.

In practice, it is desirable to give a 5 days' course of penicillin to all persons with lacerated or badly contaminated wounds involving muscle. For the severest injuries of this type it may be justifiable to give mixed gas gangrene antitoxin, by the intramuscular or intravenous route, as soon as possible after injury; an average dose is 1 ampoule (*Cl. welchii* antitoxin, 10 000 units; *Cl. œdematiens* antitoxin, 10 000 units; *Cl. septicum* antitoxin, 5,000 units). Before giving this injection, the patient should be questioned about previous serum therapy or allergy and given a trial dose of antiserum (for details *see below* under Tetanus). Local chemoprophylaxis may be used in the manner already described (*see* under Infected Wounds).

For the treatment of established gas gangrene, radical excision of affected muscle or amputation of the affected limb must be carried out at the earliest possible time. Without these measures the patient cannot benefit from chemotherapy which should always be given as well. Dosage of penicillin should be high (e.g. 1 million units every 3 or 4 hours) and continued for a week or longer. There is little evidence that antitoxin is effective in treatment, and its use is not recommended. After operation the wound may be packed with a chemotherapeutic powder (e.g. penicillin with neomycin). Blood transfusion is an important measure in the treatment of gas gangrene, especially in the presence of anæmia.

Tetanus. Like gas gangrene, tetanus is an infection caused by an anærobic spore-bearing bacillus. Here, however, a single species (*Cl. tetani*) is responsible, and the disease is due not to invasion by the organism, but to the effects of its exotoxin on the motor neurones of the central nervous system, producing characteristic muscle spasms.

Ætiology. The bacillus is a strict anærobe, which can be grown in culture by preliminary heating at 80°C for 10 minutes to kill vegetative forms and separated, often with difficulty, from other spore-bearers by its ability to swarm on the surface of agar. It is recognized by its typical "drumstick" shape, due to the terminal spore, and the diagnosis confirmed by causing tetanus, preventable by antitoxin, on injection into a mouse.

The organism is common in cultivated soil, and in the fæces of man and animals, especially in herbivora. It can be found in the injured tissues of patients with tetanus.

Tetanus may occur after quite a trivial injury[42] but in most cases there has been either severe tissue damage or a puncture wound with no drainage. The disease is more likely to occur when the wound was contaminated with manured soil, and is, therefore, particularly common in agricultural workers. Sometimes no history of injury is obtained. Occasionally tetanus may be contracted during surgical operations, from catgut, from imperfectly sterilized instruments, from talc and probably from dust.[7, 43, 44] Another risk at operation on old wounds is the germination of tetanus spores which may have been dormant there for months or years.

Pathology.[45] The symptoms of tetanus are due to the toxin produced by clostridia multiplying in the injured tissues. It causes characteristic spasms, and a mouse dies when as little as 0·0005 mg. is injected. A fluid culture of the bacilli will produce the same effects, but not if the toxins are destroyed by heat. Factors which favour gas gangrene also help to initiate tetanus, viz., a low oxidation-reduction potential, the presence of calcium ions and other accessory factors and tissue debilitants, including perhaps the

toxins of other anærobes. The growth of ærobic organisms lowers the oxidation reduction potential and is thus an accessory factor. Devitalized or necrotic tissue provides a nidus for growth, but in contrast with gas gangrene tetanus may develop in the presence of little tissue damage.

The toxin has been claimed, by different workers, to act (i) on the myoneural junction, (ii) on the proprioceptive sensory nerve ending, and (iii) on the central synapse. *The weight of evidence supports the third view* e.g. if the sciatic nerve of a rabbit is sclerosed by an irritant, injection of toxin into its calf muscles does not cause tetanic spasms. Injection of toxin into the proximal uninjured part of the sciatic nerve, however is followed by local tetanus in the calf muscles. There has also been dispute about the path by which toxin reaches the central nervous system: most of the evidence favours spread by the nerve trunks e.g. symptoms of tetanus are produced by injection of nerves with toxin, and tetanus does not occur after inoculation of toxin into a muscle if the nerve trunk supplying it is simultaneously injected with tetanus antitoxin. The opposing view that the toxin is carried in the blood stream is not supported by satisfactory evidence.

The mode of action of the toxin is not understood. There are no definite anatomical or histological signs of tetanus detectable in the central nervous system.

Clinical Findings. The incubation period varies with the site of injury from 1–21 days or occasionally longer and is usually between 7 and 14 days. After injuries to the head the incubation period is short and the prognosis particularly bad. Tetanus has sometimes occurred after operation, (e.g. for removal of a foreign body) or even after minor injury without a skin wound at the site of a wound received years before.

There is generally a history and evidence of injury which is usually penetrating or lacerated, but may be trivial. The symptoms usually begin with twitchings in the muscles of the face and neck. This is followed by spasm of the masseters and temporalis muscles, causing trismus. The corners of the mouth are pulled back, giving the "risus sardonicus." The spasm spreads to the pharyngeal muscles, causing dysphagia, and by stages to the muscles of the thorax, abdomen, back, legs, and arms. The spasm may last for a few minutes or continue for hours, and sometimes there is a continuous series of spasms. *The tonic contraction may be succeeded by clonic contractions.* The trunk may be forced into the position of *opisthotonos* (sometimes with rupture of the recti abdominis), or into anterior or lateral flexure. Spasms may be started by sensory stimuli which are often quite trivial, e.g. a noise or a bright light. There may be intense pain in the contracting muscles. Hyperpyrexia commonly occurs, and there may be retention of urine. Other symptoms are sweating, anxiety, anorexia, insomnia, and yawning.

After 4 or 5 days the patient may die from exhaustion, asphyxia, cardiac failure, or bronchopneumonia. *Prognosis is better if he lives until the seventh day.* The average mortality rate is 50–60 per cent, but much lower mortality has been recorded by some workers after careful treatment.[46, 47] *Survival is least common after injuries of the head* and a short incubation period.

In addition to the typical form of the disease, the following clinical types are described. *Local tetanus*: this is a form of the disease in which contractions occur only in the region of the wound. The prognosis for local tetanus after head wounds is good, even if general spasms supervene later. *Local tetanus has a long incubation period* (about 30 days). *Tetanus neonatorum* is a form of the disease due to infection of the

umbilical stump It is accompanied by jaundice and has a very high mortality *Puerperal tetanus* is another dangerous but extremely rare form.

Differential Diagnosis. In strychnine poisoning the muscles are relaxed between spasms this is not the case in tetanus. *Trismus* is often found in severe streptococcal tonsillitis. *Tetany* is unlikely to be mistaken for tetanus, being distinguished by the history and signs (e g., carpo-pedal spasm, Chvostek s sign, and a low serum calcium level)

Prophylaxis

PROPHYLAXIS OF THE UNINJURED In contrast with the difficulties and uncertainties of treatment, prevention of tetanus by active immunization with toxoid is both simple and effective. The value of this method was amply confirmed by experience during the Second World War [48, 49, 50] Two injections of 1 ml toxoid are given subcutaneously at an interval of 6–12 weeks, and a third injection, also of 1 ml., is given 6–12 months after the second injection. To maintain a good level of immunity a "booster" dose should be given every 5 years

In addition to its use in the Services, tetanus immunization is obviously desirable for agricultural workers and persons who are exposed to exceptional risks of injury There is also a strong case for active immunization of all infants against tetanus. This would be, in effect, a prophylaxis not only against tetanus (which causes 50–100 deaths every year in England and Wales), but also against serum sickness and other allergic reactions which often follow passive protection with antiserum. It would also solve the dilemma arising from the fact that persons previously injected with horse serum eliminate subsequently injected antitoxin from their circulation in a very short time. Combined diphtheria pertussis-tetanus prophylactics are now available and have been found effective

PROPHYLAXIS AFTER INJURY Early and effective wound toilet helps to prevent the growth of all anaerobes, including *Cl tetani*. Penicillin, topical and systemic, will add to this effect, and the former has been found to have prophylactic value in experimental mouse tetanus The principal component of defence, however is the neutralization of toxins. In those who have been actively immunized, a "booster" injection of 1 ml. toxoid is sufficient for this purpose, unless there has been a long period of delay before primary treatment.[51] For such cases, and for those who have not been actively immunized, prophylaxis, when indicated (*see* below), is by passive immunization with tetanus antiserum. To prevent anaphylactic reactions, the patient should first be questioned (*a*) for a history of asthma, infantile eczema or other allergic diseases, and (*b*) about previous serum therapy and reactions. If the answers to all of these questions are "No " the prophylactic dose of serum (1,500-3 000 units) may be given by the intra muscular route If the answer to any of them is "yes," a "trial" dose of 0·2 ml. of serum should be injected *subcutaneously* the serum being undiluted except in those who have suffered from asthma or infantile eczema, and these should first be given serum diluted 1 in 10 The patient is kept under observation for half an hour and the full prophylactic dose should then only be given if no signs of sensitivity (malaise, headache, flushing) appear in *that* time after a trial dose with undiluted serum. By this routine it should be possible to prevent anaphylaxis it is advisable, however to have a syringe and adrena line (1 in 1,000) at hand during any injection of serum, and the patient should be warned of the possible appearance of a rash and fever 3–12 days later [52]

The indications for prophylaxis after injury have been the subject of controversy In a fair proportion of cases tetanus has followed trivial injury or no known injury some authorities have therefore recommended the injection of tetanus antiserum after any perforation of the skin. A meticulous observance of this policy would involve several injections of antiserum a year for most people, with attendant risks of serum reactions (occasionally fatal) to prevent an exceedingly remote chance of tetanus, and tetanus would still sometimes occur in persons who could recall no previous injury A reasonable procedure is to give antiserum (or toxoid when allowable) for all severe or extensive wounds, and for smaller wounds if they are likely to have been contaminated with road dirt, soil, or fæces, or especially prone to sepsis (e.g. human or animal bites, and injuries for which delayed suture is required). Instructions about tetanus prophylaxis should be displayed in all Casualty Departments.

PROPHYLAXIS OF POST-OPERATIVE TETANUS. Tetanus has sometimes followed contamination of clean operation wounds. Care is required to ensure that all materials used at operations are *adequately* sterilized. Plenum ventilation should be installed in all new theatres to reduce the risks of air-borne contamination, and in all theatres an attempt should be made to prevent the accumulation of dust, and to reduce unnecessary movements.

Treatment. The treatment of tetanus is directed simultaneously towards (1) the control of spasms, (2) the neutralization of toxins, (3) the maintenance of nutrition, (4) the maintenance of respiration, (5) the prevention of pneumonia and other complications, (6) appropriate wound treatment and the elimination of tetanus bacilli, (7) treatment of complications, and other measures.

THE CONTROL OF SPASMS. This is the most vital part of the treatment, as death is caused, directly or indirectly by the spasms. The patient should be protected, as far as possible from sensory stimuli, and nursed in a darkened room with a minimum of handling and noise Two kinds of drugs are in use (*a*) central depressants, including thiopentone, pethidine, paraldehyde, pentobarbital, and tribromethanol and (*b*) neuro-muscular blocking agents, or "relaxants" these include curare (d-tubo-curarine), succinyl choline, decamethonium iodide, gallamine triethiodide, and mephenesin. Apart from the last (which is thought to act centrally) these agents may cause respiratory paralysis at dosages that control the spasms and for this reason it may be necessary to maintain respiration by positive pressure ventilation through a tracheotomy opening for long periods Food must be given by a stomach tube Treatment with curare, originally described by Spencer Wells in the last century has been developed in recent years, especially by Danish workers,[43] who have adopted a regime previously found to be valuable in the treatment of bulbar poliomyelitis. For a detailed account of the techniques, which are elaborate and require special staff facilities, the reader should consult the original papers (*see also* [44, 45, 46])

Successful treatment without the use of relaxants has been described by other workers, notably Forbes and Auld (1955),[46] who handled fifteen cases in this way without one death. They treated their patients with light anæsthesia, supplemented in some cases by tracheotomy and with relaxants available if necessary A convenient method (*see also* Batten, 1956[47]) is to introduce an intravenous cannula under rectal thiopentone (1 g. in 5 per cent solution), and to administer thiopentone by intravenous drip continuously for 14 days or longer 1–2 grams of thiopentone in 24 hours may be required to control

the spasms. During the recovery period oral paraldehyde or another barbiturate may be given Prolonged nitrous oxide anæsthesia should *not* be used, as it may cause severe bone marrow depression These methods have been criticized on the grounds that the prolonged periods of unconsciousness which they entail predispose the patient towards respiratory infections. Chlorpromazine has been shown to control the spasms of tetanus without causing loss of consciousness, and its value, particularly in combination with other drugs, requires further study [34]

NEUTRALIZATION OF TOXINS. The therapeutic value of antitoxin is still unproven. It seems probable that tetanus toxin cannot be neutralized by injected antitoxins once it is fixed on motor nerve cells antitoxin, however should protect the central nervous system from further damage by combining with unfixed toxin in the tissues.

In treatment, a trial dose of antitoxin (*see* above) should be given by the subcutaneous route if no reaction occurs, 100 000–200,000 international units of antitoxin should be given slowly by the *intravenous* route. Some authorities recommend a local injection of 5 000 units around the wound as well. Intrathecal antitoxin is probably of no therapeutic value it may cause severe reactions and has been discarded.[44]

NUTRITION. Nutrition must be adequately maintained there is evidence that the need for calories is increased in tetanus, and water and electrolyte balance is liable to be dangerously upset unless it is kept under control

A nasal catheter should be passed to the stomach with the aid of a relaxant given intravenously [87] The catheter should be changed frequently to avoid ulceration. Wilson and Care (1955)[89] used the following mixture, 900 ml. of the gruel being given as a continuous drip in 24 hours

1½ pints fresh milk
2 eggs
4½ oz. glucose
1 oz. "Casilan"
2 oz. dried milk
1 teaspoonful "Marmite"
1 tablet (100 mg.) ascorbic acid
½ teaspoonful salt

This provides 1,500 calories. A further 300–600 calories are given daily in 2–4 litres of the following solution given intravenously through a catheter glucose, 33 gm. sodium chloride, 3 gm. potassium chloride 1 gm. calcium chloride, 0·2 gm. magnesium chloride, 0·1 gm. in 1 litre of distilled water The serum electrolytes should be estimated frequently so that adjustments of input can be made if necessary

MAINTENANCE OF RESPIRATION Respiration may be obstructed by laryngospasm and by accumulation of secretions, and it is often necessary to perform a tracheotomy Bronchial secretions should be removed by suction through the tracheotomy opening. Artificial respiration by positive pressure through a tracheotomy tube is part of the routine procedure of treatment with relaxants.

PREVENTION OF PNEUMONIA. For this purpose two measures are needed first, the maintenance of adequate respiration and removal of bronchial secretions and second, chemotherapy with penicillin (1 million units daily by intramuscular injection). The patient should be nursed in a semi prone position, and turned at least once every hour

TREATMENT OF THE WOUND. The evidence[44] suggests that wound excision does little or nothing to mitigate the course of tetanus once the symptoms have appeared it may indeed, cause more harm by precipitating tetanic spasms. Each case must be considered on its merits, but the minimum of surgery consistent with the principles of wound treat ment should be undertaken

Penicillin is given primarily to prevent respiratory infection, but it has been shown that tetanus bacilli may disappear from the wound after a course of the antibiotic. In animals, penicillin cannot prevent tetanus, even when it is injected at the same time as tetanus bacilli If a mixed infection is present in the wound, tetracycline may be the antibiotic of choice. Local application of penicillin powder or of bacitracin may be helpful. Meleney[7] has found that zinc peroxide powder destroys not only the clostridia but also their toxins it may therefore be a suitable agent to apply to the wound in tetanus.

OTHER MEASURES. The treatment of tetanus demands high standards of nursing and medical supervision. Complications which may call for special treatment are the bitten tongue vertebral fractures, and other injuries from uncontrolled movements serum sickness mediastinal emphysema and pneumothorax following tracheotomy aspira tion pneumonia myocardial failure fæcal impaction urinary retention bedsores inadequate or excessive sedation and failure to control disturbances of fluid, electrolyte, and nutritional balance

References

NOTE. Until recently the bulk of the literature on clinical aspects on the prevention and treatment of wound infection has been derived from experience in war surgery Since the 1939–1945 war much attention has been focused on the role of chemotherapy Interest in the application of basic principles of surgical care has developed, particularly in relation to industrial hand injuries and to open fractures of the limbs. More general references to the literature on clinical considerations are given in the first section of the bibliography Section II contains references on bacteriological aspects of wound infections. Further references on chemotherapy are presented in the bibliography to Volume 3 Chapter 15

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CHAPTER IV

ACUTE FRACTURES AND DISLOCATIONS

JOHN M. P CLARK

I

INTRODUCTION

ANY attempt to cover in a single essay so wide a field as that of the treatment of acute fractures and dislocations must inevitably mean condensation and rather arbitrary selection If there be nearly general agreement on the broad principles of traumatic surgery the application of those principles must necessarily vary with the individual craftsman, his ability and his experience. It is impossible to hand on experience as such and all apprentices eventually gain their own skill by making their own mistakes, and by repeating them together with those of their predecessors. At best it is only possible for the instructor to advise and to indicate a way to be followed. The teacher's craftsmanship must be ripe and yet his mind must still be open to new ideas and modifications. It is equally likely that disaster will result from the entrenched conservatism of the older man as from the rash intrepidity of the younger Whilst it is hoped that reasonable consideration of the tried methods of treating fractures and dislocations is given here it is clear that the bias will lie on the side of the methods judged best in the writer's hands and used by him and his colleagues in their department. Such indications, though a thought dogmatic, are intended to help the reader to take a definite line of action until his own experience has taught him what is best suited to his peculiar propensity

II

GENERAL CONSIDERATIONS

(1) Causes and Varieties of Fractures

Fractures are either traumatic or pathological. In the first category the force applied to the bone is the entire cause of the fracture In the second group the bone has first been weakened to such a degree that the external force is a minor factor responsible for precipitating the final break and it is insufficient in power to fracture a normal bone. Nevertheless in traumatic fractures there are predisposing causes although they are not pathological processes. Increased expectation of life means that osteoporosis is now the commonest reason for bones to be more susceptible to fracture, especially in women after the menopause, and the neck of the femur the lower end of the radius, and the upper lumbar spine are the usual sites of fracture During childhood the presence of epiphyseal cartilage in growing bones gives relative instability at such points and favours fracture-separation of epiphyses these lesions happen most frequently in the region of the elbow The hazards of occupation often determine the site and nature of bony

injury Coal mining is the main source of fracture-dislocation of the spine falls from a height produce fractures of the calcaneum, pelvis, and lumbar spine in that order depending on the force of the impact motoring (particularly when unprotected as on a motor cycle) yields multiple gross fractures and injuries of all descriptions in any part of the body

(a) TRAUMATIC FRACTURES. There is a direct relationship between the type and degree of force applied and the nature of the fracture produced, the amount of soft tissue damaged and the presence or absence of a wound communicating with the fracture. The division of fractures into open and closed is of first importance because the wound in the open fracture must take precedence in treatment over all else. A direct blow to a long bone may produce a transverse fracture without soft tissue damage but, if the force should continue, the injury to the surrounding tissues will be severe. The bones of the leg or forearm are often twisted because force is applied to the body whilst the foot is fixed to the ground or the hand is fixed through taking the first impact of a fall such violence causes the bones to break at their weakest points and gives spiral fractures in the two bones at different levels. Wrenching of the foot into eversion during weight bearing is responsible for producing a combined hinge fracture of the lower end of the fibula and a traction fracture of the medial malleolus. Compression fractures are seen in the vertebral bodies when force is applied to the flexed back, and also in the ends of the fragments of impacted fractures and in the crushed calcaneum after a fall from a height. Distraction fractures occur in the patella and olecranon when the bone breaks in consequence of sudden muscular effort. Greenstick fractures occur in children and the bone is bent and splintered on the convexity and impacted on the concavity of the bend. The fissured fracture is usually longitudinal near a joint surface and is typically encountered across the waist of the carpal scaphoid (Fig. 22).

(b) SPONTANEOUS FRACTURES. Fatigue fractures result from ordinary activities either repeated for an indefinite period of time in trained individuals or from the sudden accession of activity in untrained people. Single or multiple bones may be affected. The march fracture occurs in the neck of the second metatarsal, most often in recruits. The condition may obtain in the normal foot but the short first metatarsal of metatarsus primus varus is a predisposing cause because of the vicarious load thrown on to the second metatarsal Fatigue fracture of the fibula occurs in long distance runners at the weakest point of the bone at about the junction of the middle and lower thirds of the shaft. High fibular fractures result from repeated jumping or skipping. Fatigue fractures of the tibia are found at the middle of the bone they are transverse fissures and occur in young healthy ballet dancers. Fatigue fractures in the upper limb are uncommon but are met with in the ulna, and very occasionally in the radius, after shovelling or doing farm work. Fatigue fractures of the ribs may result from coughing and are located at the site of interdigitation of the external oblique and serratus anterior muscles late pregnancy predisposes because the lower ribs are everted by the enlarging uterus. Fits and tabes dorsalis may be responsible for spontaneous fractures as a consequence of uncontrolled or violent muscular action. In the flail limb after poliomyelitis the bones are not only more fragile but they lack the protective support of active muscles and are therefore more susceptible to fracture

(c) BIRTH FRACTURES. The fœtal humerus is most commonly fractured at the middle of the bone during delivery of extended arms in breech presentations The middle of the

clavicle is prone to fracture under the accoucheur's finger whilst he is endeavouring to deliver the after-coming head. Fracture of the shaft of the femur usually occurs in a breech presentation with extended legs because of the barrier they offer to delivery

(d) PATHOLOGICAL FRACTURES. These fractures are readily suspected when the trauma has been minimal but their true nature is more easily missed when a definite accident has taken place. The history of previous fractures or of previous treatment for disease or physical handicap may supply a clear clue to the real cause of the fracture

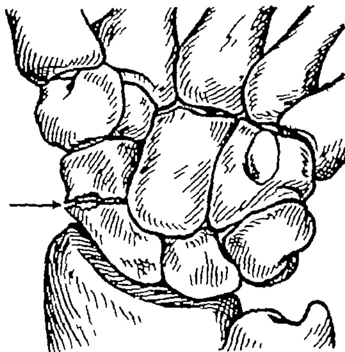


FIG. 22. Fracture of the carpal scaphoid.

but quite often it is the radiograph of the injured bone which first discloses evidence of local disease. Although the defective bones may fracture more easily they heal normally except in the presence of chronic pyogenic or syphilitic osteomyelitis. Primary and secondary neoplasms do not affect the rate of union of fractures and in Paget's disease and local bone cyst healing may even be accelerated. Rare causes of pathological fracture, in addition to benign and malignant tumours, include fragilitas ossium, dyschondroplasia, scurvy rickets, osteomalacia, cœliac disease, renal rickets, hyperparathyroidism, and fibrous dysplasia.

(2) Mechanism of Union

The first phase of bone union differs in no way from the healing of any clean wound. It is only the need to re-establish a rigid prop by laying down fresh bone that makes the subsequent phases of union a peculiar process. Immediately after injury the bone ends are quickly surrounded by blood from the torn periosteal and marrow vessels and from the blood vessels in the Haversian canals. The circulation in the bone ends ceases until

the level of the first anastomosis of vessels is reached and this causes death of the osteocytes in the area deprived of blood supply Similarly there is necrosis of periosteum and marrow tissue on each side of the fracture. The accumulated blood then clots and so far from participating in healing of the bone, it is actually a hindrance. The clot has to be pushed out of the way by growing callus and is gradually invaded by cells which from the first are osteogenic and are not derived from any osteoid changes in the clot.

Within 24 hours the osteogenic or cambium layer of the periosteum proliferates and lifts the fibrous outer layer away from the bone. During the next few days these osteogenic periosteal cells proliferate to such an extent that they form a collar of callus around each fragment close to the fracture The osteogenic cells of this callus are converted into osteoblasts within 2 days of the injury and a deposit of new bone is immediately added to the outer surface of the fragment in the deepest part of the collar As the collar adds further layers of bone the osteoblasts become osteocytes. In the more superficial layers of the collars, where the blood supply is less, the osteogenic cells differentiate into chondroblasts and then form cartilage. As repair continues the collars on the fragments enlarge and merge to form external callus. The cartilage cells secrete phosphatase which enables the surrounding intercellular substance to calcify and imprison the cartilage cells so that they die leaving spaces into which capillaries and osteogenic cells will grow from the already formed deeper new bone trabeculæ. Simultaneously internal callus is formed from the endosteum of the marrow cavity and from the undifferentiated mother cells of the marrow If the fragments are immobilized and repeated disturbance of the new capillaries is avoided union will proceed in this orderly fashion and the bone ends will be bound together rigidly enough to prevent bending or displacement, all local tenderness and springiness of the bones will have disappeared and clinical union will be present. Failure to immobilize the fragments properly will mean that the collars of osteogenic tissue will fail to merge and fibroblasts will invade the fracture area and repair it with fibrous tissue.

The final stage of bone union consists of remodelling of the callus. The dead portions of the original fragments are slowly resorbed and replaced by trabeculæ. The cancellous bone which is in direct line between the fragments is gradually converted into compact bone and the trabeculæ of the external and internal callus are then no longer required and are gradually resorbed until the fracture site, in a properly reduced fracture may be radiographically difficult to detect.

The process of repair is subject to modification and the time taken for each phase varies with the individual bones, the age of the patient, the type of fracture, whether the fracture is metaphyseal or diaphyseal and the amount of displacement of the fracture ends. The quickest union takes place in the presence of good apposition and immobilization of the fragments and it is analogous to the healing of a wound by first intention. Poor apposition of the fragments, distraction of the bone ends, and gross comminution with gaps all require large amounts of callus, there is delay in consolidation and this is analogous to healing of a wound by granulation. A most potent factor in altering the course of repair is any unhealed or infected wound because of the perpetuation and intensification of local hyperæmia. Control of infection is essential and reduction of the hyperæmia must obtain before solidification of the callus can begin. Eventually infected fractures will unite if they are immobilized for long enough and sequestra are removed as soon as they are formed. Union cannot be expected unless an adequate blood supply

remains in each fragment. The carpal scaphoid, the talus, the lower third of the tibia, and of the humerus are all sites where one fragment may be cut off from its nutrient artery with consequent prejudice to its blood supply and much delay in union. Avascularity of a fragment, as in the femoral head after fracture of the femoral neck, will result in aseptic necrosis and quiet sequestration. A dead fragment can take no part in any repair (Fig. 23).

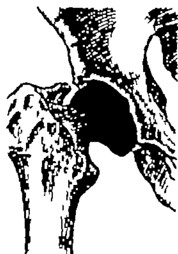


FIG. 23. Aseptic necrosis of the femoral head.



FIG. 24. Forward dislocation of the shoulder

(3) Dislocations and Subluxations

Sudden violence exerted upon a joint may disturb its component bones. Such force is rarely applied directly to the joint but usually indirectly by leverage of the bones. The dislocating drive is commonly external but sudden and excessive muscular action, as in the shoulder and temporo-mandibular joints, may be great enough to damage ligaments and cause displacement. Complete dislocation means complete loss of apposition, and subluxation means incomplete loss of apposition of the articular surfaces (Fig. 24). As with fractures the open dislocation is of greater concern than the closed. The presence of a wound which communicates with the displaced bones inevitably means a contaminated joint and the risk of infection is greatly reduced by quickly obtaining skin closure.

Dislocations are frequently complicated by nerve injury from compression or traction. Gross injury to blood vessels is rare and the brachial artery is the one most commonly affected. The trauma or the continued displacement of the bones may however provoke arterial spasm with all its possible dangerous sequelæ

The anatomical formation of joints is a considerable determinant of dislocation. A joint such as the shoulder which relies for its integrity chiefly on muscles and ligaments, is much more prone to dislocation than a strong interlocking joint such as the hip In some sites, as in the ankle dislocation must be complicated by fracture before any displacement of the joint can occur

Subluxation of a joint is readily overlooked both as a primary lesion and as an incomplete reduction of a previously complete dislocation Since a considerable range of apparently normal movement may be possible in the presence of subluxation the true nature of any restriction of movement may not be appreciated until post traumatic



FIG. 25 Subluxation of the interphalangeal joint of the finger

oedema has subsided and the real range of movement can be properly assessed. This is particularly true of finger joints whose ligaments are radial and in which the full range of movement will be obstructed unless the congruity of the articular surfaces is absolute (Fig. 25) A restricted range of free, painless movement is often available in subluxations and so renders the diagnosis obscure. Immediate recoil of the dislocated parts may occur spontaneously after an accident, as not infrequently happens in the cervical spine. During the excursion of the displaced vertebræ irremediable damage to the spinal cord may take place and leave a tetraplegia without apparent bony injury or displacement of the cervical spine.

Most dislocations can be accurately replaced and ultimately good function is to be expected. Tearing of the capsule may cut off the blood supply to some part of the joint and aseptic necrosis may supervene. This complication occurs at the time of the injury but it will not be radiographically demonstrable until weeks later Recurrent dislocation may result from incomplete healing of a torn capsule and its ligaments. An unreduced dislocation will form a false joint in the position of dislocation and the muscles and ligaments will adapt themselves so that diminished, but perhaps painless function, may ensue.

(4) Diagnosis

The clues to diagnosis are supplied by the history symptoms, and clinical signs confirmation is afforded by radiography Fractures in smaller bones may be temporarily missed in patients suffering from shock or who have sustained multiple injuries. The persistence of pain after any injury however slight, warrants further investigation because

of the possible injury to bone. Fractures typically cause intermittent spasms of pain through attempted movement or by the relaxation of muscular fixation when the patient is recumbent. A fracture, by loss of skeletal support, may be expected to show deformity and loss of function and there may be damage to the soft parts but all these signs may be insignificant or absent.

The provisional diagnosis of fracture ought to be made, as far as possible, by inspection alone. Palpation may be of help by the detection of swelling, or by eliciting tenderness, it may localize a fracture in a bone which shows no displacement or deformity. Once the fracture is suspected it is better to refrain from further physical examination until a radiograph has been taken. Inspection is likely to discover local swelling, perhaps blisters and bruising of the skin, and an alteration in contour. Displacement of the fragments of a fracture, however caused, can be detected by noting shortening because of overlap or lengthening because of distraction (as in the patella or olecranon). Angulation is responsible for gross visible deformity. Lateral rotation or torsion always shows in the lower limb, because of the effect of its weight. Rotational deformity is also usually encountered in the forearm. Lateral displacement is often palpable and even visible on the subcutaneous surface of a bone. Displacements are readily discerned by comparing the affected limb with its fellow but elaborate measurements are of little help and do not warrant the disturbance of the injured part. Loss of function is manifested by the patient. It ought not to be necessary to elicit the other two classical signs of fracture, namely preternatural mobility and crepitus.

Radiography in the diagnosis of fracture or dislocation is indispensable and it is required as an emergency measure. Medico-legally the onus of refusing X ray examination of an injured part in the first instance must be thrown on to the patient and must not lie with the doctor. The exclusion of the diagnosis of fracture after even the slightest injury cannot be completed without radiography. Any attempt to treat a fracture without accurate knowledge of the exact nature of the bony injury is wholly inexcusable because it is a wilful endeavour to perform blindly a manœuvre which can and must be previously charted. The first radiographs will show the type of fracture, the displacement and number of the fragments and, from the nature of the fracture, will indicate the action of the deforming force, and therefore the direction of the reducing force that manipulation or traction must apply. The clinical diagnosis of a dislocation is not a signal to manipulate, because a radiograph will often show a concomitant fracture which may either prevent reduction of the dislocation or render the reduction unstable: there may be a partly displaced articular bone end which is apt to be completely displaced by injudicious passive movement. Radiographs of all sites of presumptive fracture must be taken in two planes at right angles to one another. It is advisable to include the joints above and below because in a long bone a fracture may otherwise be missed altogether. In the leg and forearm a fracture of one bone is frequently paired with a fracture or dislocation of the other bone. The habit of taking only antero-posterior radiographs of the hip or shoulder is to be strongly deprecated because often a fracture or dislocation is visible only on the lateral radiograph of the one or the vertical radiograph of the other. In some situations special supplementary views will be required. An oblique view of the carpal scaphoid is obligatory if the absolute elimination of fracture is to be achieved. An axial view of the patella is required if the articular surface of the bone is to be studied without the intrusion of the overlap of the other bones. Oblique views of the spine are needed to

demonstrate the neural arch, the articular processes and the pars interarticularis of a vertebra. Instability of the joints in the absence of fracture of the constituent bones is best demonstrated by radiographs taken whilst the joint is subjected to stress. Thus a ruptured medial lateral ligament of the knee permits unnatural separation of the articular surfaces of the joint and a similar injury of the ankle enables the talus to be tilted to an abnormal degree or a diastasis of the inferior tibio-fibular joint to be demonstrated (Fig. 26). The recoil mechanism in the displaced cervical spine, which may operate

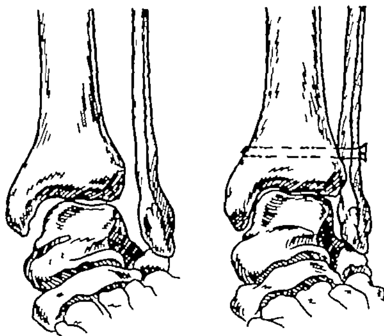


FIG. 26. Diastasis of the inferior tibio-fibular joint.

after an accident severe enough perhaps to have caused a tetraplegia, may only be exhibited by radiographs of the flexed neck. In composite areas, such as the pelvis, in relation to the sacro-iliac joints, stereoscopic pictures may elucidate appearances difficult to interpret on the ordinary radiograph. In some instances, especially so in the carpal scaphoid, a crack fracture may be so minute as to be invisible on the initial radiographs. X-ray examination must be repeated after a fortnight because such cracks will by then have become discernible

III

GENERAL PRINCIPLES OF TREATMENT

(5) Traumatic Shock

Traumatic shock is a condition common to many types of physical injury and varies mainly in degree rather than in kind. Shock is a total bodily reaction to a sudden injury to a part of the body. This clinical state is the expression of an upset of the normal physiological balance in the vascular system. There are three causes for the disparity

which thus arises between the volume of the circulating blood and the capacity of the vascular bed

(a) BLOOD LOSS. Frank loss of whole blood externally is the least complicated form of shock and its replacement by whole blood is essential. Red cells offer bulk and carry oxygen and are retained in the circulation. Fluid replacement by glucose saline or any "plasma expander" is rapidly lost from the circulation and is useful only to cover an emergency until blood transfusion can be started. Blood loss into the injured part often accounts for very large volumes of blood, notably in retroperitoneal and pelvic hæmorrhages. In all injured parts there is swelling produced by blood or traumatic œdema. The leaking of the fluid complement of blood into the intercellular spaces will concentrate the intravascular blood of the injured part even to the point of agglutination further to provoke tissue anoxia and hence additional shock.

(b) INCREASE IN THE VASCULAR BED Loss of tone in the peripheral vessels enormously increases the capacity of the vascular bed. Pain and anxiety directly promote relaxation of the vascular walls, toxic products of devitalized tissues and of bacteria favour vaso-dilatation, particularly of the capillary bed thus reducing still further the effective blood volume and the consequent tissue anoxia assists in yet more stagnation of blood.

(c) CIRCULATORY FAILURE. Heart failure may be the direct initial response to acute shock. More often it is the result of a diminished return of blood to the right side of the heart because of the increase in the capacity of the capillary bed as a consequence of loss of vascular tone. The inevitable reduction in cardiac output adds to the circulatory difficulties.

The most trivial injury can produce shock out of all proportion to its size as a result of psychogenic stimuli but usually the degree of injury and shock are commensurate and based on physiological imbalance. Oligæmia in the early stages of shock is not directly measurable because it is greater than the clinical tests indicate. The early diminution of blood volume is compensated by local and general vaso-constriction and it is to be expected that the pulse will be accelerated and hard. The failure of this constrictive and protective mechanism will cause the blood pressure to fall which in turn will stimulate the carotid and aortic arch reflexes to produce further vaso-constriction and cardiac acceleration. This is a reversible state of shock and complete recovery is possible either spontaneously or after blood transfusion. In uncompensated shock the vascular reflexes are inadequate and the blood pressure remains low tissue anoxia leads to capillary dilation, transudation of plasma and further reduction of blood volume. Decompensated shock may be irreversible and reveals itself clinically by reduction of blood pressure, fall in temperature, smallness of the volume of the pulse, sighing respirations, cold clammy skin and grey pallor with blueness of the extremities.

Assessment of Blood Loss In open injuries blood loss is to be taken for granted, is not really assessable but must be assumed to be large and to require blood transfusion In closed injuries the blood loss is roughly parallel with the size of the primary swelling. Closed fractures and injuries to the soft parts of the ankle, knee or forearm are usually associated with a blood loss into the part of ½–1 pint (less than 10 per cent of the total blood volume) and such patients do not require transfusion. In multiple injuries, each of such injuries will contribute its quota to the total blood loss. Fractures of the shaft of the femur major fractures of the tibia and fibula, and of the upper arm tend to yield a

blood loss of 1-3 pints or 10-30 per cent of the total blood volume Transfusion of blood is required for all patients whose estimated blood loss is 2 pints. Fractures of the pelvis and trunk, even without visceral damage, may cause loss of large quantities of blood, up to 40-50 per cent of the total blood volume. In severe multiple lesions there are nearly always some open fractures and therefore additional blood loss will occur externally Most patients suffering from open fractures (other than the small puncture wounds from within) come into the category of major wounds and will require transfusion

The loss of 2 pints of blood ought to be regarded as the top limit that can be safely tolerated by any patient. If there be any doubt whether a transfusion is to be given it can be quickly resolved by transfusing. The risks of over-transfusion are theoretical rather than practical. It may be safely assumed that the amount of blood lost in the presence of fractures is nearly always greater than is usually recognized but it can in the absence of clinical signs of oligaemia, be roughly predicted by the rough guide already given. Shock anticipated is shock best treated.

(6) Open Fractures

An open fracture communicates with the outer air through a breach in the skin. The first and most serious variety of open fracture is produced by a direct force which crushes and devitalizes the overlying skin and soft tissues. In the second variety the skin is punctured from within by one of the bone fragments and it is rare for the soft parts to be greatly damaged. The third variety is the secondary open fracture caused by sloughing of the skin later and often it is related to sepsis.

An open fracture is a surgical emergency to be dealt with in the operating theatre after shock has been fully checked. After removal of the clothing the skin surrounding the wound is cleansed with detergents before the patient enters the theatre but no antiseptics must be in contact with the wound All wounds are contaminated, and therefore, potentially infected, but a proper surgical toilet of the wound, fortified by the use of antibiotics to inhibit the proliferation of organisms, ought to lead to healing by first intention. The aim of immediate operation is to explore the wound in all its ramifications. If necessary the wound may be enlarged in the long axis of the limb and the deep fascia divided to afford full inspection. Important structures may be damaged in addition to bone and may require immediate repair Foreign material and damaged tissue must be removed and tension in the depths of the wound must be relieved. Tension if allowed to remain, promotes ischaemia and tissue death it is the most potent factor in encouraging unavoidable contamination to blossom into infection. Completely detached small fragments of bone are best removed but too liberal excision of bone is to be avoided. Many loose pieces of bone are viable and, in a non-infected wound will act as chip grafts and do much to bridge gaps and to prevent delayed union of the fracture. Larger pieces of bone with muscle attached must be replaced and, if necessary held in place by internal fixation. Muscle attachment gives a greater chance for the bone fragment to survive. The comminuted fracture will often have a better prognosis for union than apparently much less formidable bone injuries.

It is essential to save every scrap of healthy skin in the hope that, after removal of dirty and devitalized tissue and by decompression of the injured limb it will be possible to approximate the skin edges without tension. The skin must not be drawn tightly over

a cavity like a drumhead because it will probably slough later and any residual contaminant organisms, especially anaerobes, can thrive in the dead space. A wound over the subcutaneous aspect of a bone can often be closed satisfactorily if relieving incisions are made over other aspects of the limb The consequent skin defects can be quickly covered with split-skin grafts. The attempt to achieve primary closure of the wound *must not permit risks to be taken in the hope of producing a featureless scar and rapid* healing. Resolution of post-traumatic and post-operative swelling will often allow delayed primary suture to be performed in a few days. Even slow healing by granulation is preferable to the dangers of deep sepsis and later sloughing of the skin. Wounds with extensive skin loss must be provided with skin cover as soon as it is compatible with safety because of the delay in union of fractures which lack a dressing of skin. Full function cannot be restored to a limb in the presence of an unhealed wound.

The use of antibiotic drugs is the second line of defence after the proper surgical treatment of the wound. Swabs from the wounds are examined bacteriologically and the sensitivity of the organisms to individual antibiotics is determined so that the appropriate one may be given. Anaerobes are always to be feared and anti-gas gangrene serum has no prophylactic value. Although the use of prophylactic serum reduced the incidence of tetanus during the war the disease still accounts for about sixty civilian deaths each year in Great Britain.

After dealing with the wound, the fracture has then to be immobilized even though definitive reduction may have to be postponed until after the wound has healed. For fractures in which full reduction has not been satisfactorily achieved internal fixation with plates or screws can be safely considered when the proper treatment of the wound has gone forward. The prejudice against introducing metal into a fresh open fracture *is not entirely supported by the results of good surgery in civil injuries. The complete* immobilization of a fracture, in reducing shock and promoting healing of the wound, offsets any delay in bony union which the use of foreign material may entail. The plating of an open fracture is not advocated as a routine measure but, on occasion, it has real advantages to offer

(7) Penetrating Wounds of Joints

Joint cavities are spaces whose walls and contents differ in structure and blood supply their reaction to infection and capacity for repair Adult articular cartilage is avascular and consequently its repair and power of regeneration are very poor The preservation of joint function depends directly on the extent to which the articular cartilage approaches the normal after it has been damaged and repaired. The nutrition of articular cartilage and menisci is very largely derived from the synovial fluid. Normal synovial fluid is mildly bactericidal but stale fluid mixed with blood is an excellent medium for bacterial growth. The synovial membrane is a barrier against infection by reason of its abundant blood supply and its secretion of synovial fluid it is also a barrier to the transmission of drugs from the blood stream to the joint except for penicillin. Subchondral infection interferes with the blood supply to articular cartilage and infection of the synovial fluid interferes with cartilage nutrition and so the cartilage is destroyed Synovial membrane reacts to infection by forming inflammatory adhesions which tend to localize the infection but later restrict the final range of joint movement. Purulent arthritis destroys articular cartilage which is then replaced by granulation tissue. The

first areas of articular cartilage to suffer destruction are those in contact with each other they quickly perforate and necrosis of the underlying bone ensues

Closure of the perforated joint is needed as urgently as closure of the open fracture The wound must be surgically cleaned at all levels down to and including the joint. If the operation can be done within a few hours of injury whilst the wound is still but contaminated, joint and skin can be fully closed in safety If there be reason to believe that infection is already established then it is best to close only the synovial and capsular layers of the wound and to leave the skin open for 3 or 4 days. Delayed primary suture of the skin is performed when it is certain that there has been no spread of infection from the extra-capsular tissues into the joint. Drainage of joints is only indicated when there is an established purulent infection and all hope of avoiding ankylosis of the joint has been abandoned. Even when the widest possible drainage of the joint is required, removal of part of the constituent bones of the joint ought, if possible, to be avoided. Excision of the head of the femur or humerus or removal of the talus can only be countenanced if sequestration has occurred or when the patient's life is in danger Instability of the joint and shortening of the limb are a worse functional result than ankylosis of the joint in its optimum position for function and this is the goal to be aimed at when disorganization of the joint is inevitable.

In the majority of patients the invading organisms will be sensitive to penicillin given systemically In the face of a rising temperature and pulse rate after primary or delayed primary closure, aspiration of the joint, and bacteriological examination of the aspirate are required so that the sensitivity of the invading organisms to individual antibiotics can be estimated. When the organisms are insensitive to penicillin the appropriate antibiotic must be injected into the joint after further aspiration. Complete immobilization of the infected joint is essential and preferably not by the use of an occlusive material such as plaster of Paris. Any uncertainty of progress either locally or generally demands inspection of the wound, aspiration of the joint, and replacement with antibiotic ease of access to the joint is then obligatory

Injury to a joint causes reactionary or inflammatory swelling and reflex muscle spasm. Joint stiffness results from shortening of peri-articular structures, organization of intra-articular adhesions and peri-articular fibrosis Immobilization of the injured or infected joint must be continued until swelling of the joint has subsided and muscle spasm has gone. Resumption of activity must be gradual and under supervision. The re-appearance of swelling or the return of muscle spasm indicates that further rest is required. The presence of a fracture into the perforated joint makes little difference to the treatment of the joint but it does increase the likelihood that restriction of movement of the joint will mar the final result.

(8) Vascular Complications

Arterial injury in association with a fracture or dislocation is caused by contusion, laceration, traction, or rupture. Vascular complications are not common but they are a true emergency because they endanger the limb or even life. Repair of the vessel within 6–8 hours of injury materially increases the chances of success. An artery may be completely severed, lacerated transversely or longitudinally punctured, or it may bleed into its wall or undergo tight and persistent spasm of a segment. The dangers of arterial injury are firstly loss of blood and secondly arterial obstruction. The risk of exsanguination

is very small and, under ordinary circumstances, the leak can be stopped and the blood loss replaced. Unrelieved arterial obstruction will mean death of all the muscular tissue cut off from its blood supply Complete stoppage of all blood to a peripheral part for about 24 hours will cause mass gangrene Arterial obstruction for shorter periods will cause muscle necrosis of either the whole limb distal to the obstruction or of a section of a limb

The diagnosis of a severed artery may be obscured by the vessel having retracted and sealed itself with a clot. Lacerated arteries tend to bleed profusely and continuously because the retraction of the arterial wall tends to open the wound instead of sealing it. In open fractures there may be no hæmatoma because the wound allows the blood to escape. The hæmatoma in closed fractures depends as much on the distensibility of the local tissues as on the size of the artery and the nature of the arterial wound.

The signs of arterial injury are the absence of pulses and the changed appearance of the extremity Complete arterial obstruction leaves the distal part of the limb white and cool. The capillary return is very slow in comparison with that of the normal limb and there is slow venous filling. Within 2 hours after injury there is a diminution of sensation and later complete anæsthesia. Lacerations or punctures produce an hæmatoma which will organize and may form a false aneurysm in the shape of a pulsating sac in communication with the artery Injury to the arterial wall may cause a true aneurysm. Injury to an artery and its companion vein may produce an arterio-venous aneurysm. Crush injuries of the hand or foot are common and very important because so many small arteries tend to be ruptured. In the absence of a wound, tense swelling of the part arises and, if not relieved by prompt fasciotomy will cause ischæmia and permanent disability Apart from gross crushing of a part the two arteries most vulnerable are the popliteal and the brachial at the elbow Rupture of the brachial artery in association with dislocation of the elbow or supracondylar fracture of the humerus is probably more common than is supposed. Hæmorrhage into the closed cubital fossa is dangerous because it may block the collateral blood supply required when the brachial artery is severed and consequently there is a risk of gangrene or of Volkmann's contracture. A severed brachial artery ought always to be suspected in the presence of a wound in the cubital fossa or an open fracture. Swelling and ecchymosis about the elbow in closed injuries is to be expected but it is not usual for the radial and ulnar pulses to be obliterated unless the elbow has been flexed too much during the initial treatment. When the radial and ulnar pulses are obliterated then close watch on the state of the hand is urgent lest it be necessary to explore the front of the elbow to determine the exact nature of any arterial damage.

When a major vascular injury is suspected, the first call is to stop further blood loss and to treat the shock. Manual pressure, packing of the wound, and compression of the bleeding point with artery forceps will control the blood loss. A tourniquet is to be avoided at all costs because it also stops the collateral circulation Elevation of the limb will increase the risk of ischæmia, the application of heat will favour vaso-dilatation and so promote shock cold is of no benefit and may be detrimental to the life of the part distal to the arterial injury After the control of blood loss and resuscitation of the patient then the injured vessel must be freely exposed surgically The exposure must first be of the artery proximal to the injury so that blood loss can be controlled during the operation. Small lacerations of the artery can be mended by suturing with silk.

Transection or near transection require end to-end anastomosis and damaged portions of the vessel wall ought to be removed. Arterial or venous grafts will be required to bridge gaps. Ligation of vessels, even in the upper arm, usually lead to some degree of gangrene and, therefore some form of amputation. The belief that almost any vessel of the upper extremity may be ligated with impunity is erroneous. A fracture associated with transection of a major artery even after arterial repair carries a grave prognosis for the life of the limb below It has been estimated from treating vascular injuries in World War II that there is a 50 per cent amputation rate after arterial repair and 60–70 per cent rate after ligation Anticoagulants after operations for vascular repair are contra indicated because they favour severe swelling with the consequent need for secondary suture. Paravertebral block is unlikely to help a divided artery because in effect a peri arterial sympathectomy has already been done, but it may help to dilate the collateral circulation.

When the cause of the arterial obstruction is found to be segmental spasm of the vessel it may happen that exposure of the artery of itself may produce relaxation of the spasm.

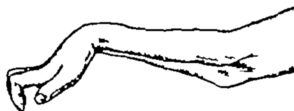


FIG. 27 Volkmann's ischaemic contracture.

Injection of papaverine (2–2½ per cent) or of procaine into the lumen of the artery may be of material benefit. Arterectomy for uncomplicated arterial spasm must never be performed. Paravertebral sympathetic block is a useful adjunct in opening up collateral circulation.

Volkmann's ischaemic contracture in the forearm is usually associated with a supra condylar fracture of the humerus which has caused injury to the brachial artery It is the direct result of arterial obstruction and is rarely caused by external constriction. The forearm muscles shorten because their fibres die and are replaced by fibrous tissue. The common deformity produced is flexion of the wrist, hyperextension of the metacarpo-phalangeal joints and flexion of the interphalangeal joints (Fig. 27) The only treatment of any real value for this permanently crippling condition is prevention by awareness of the potential complication and by close observation of the limb after injury and par ticularly after manipulative reduction of the associated fracture The diagnosis of the impending complication is really that of arterial obstruction. Pain is usual but it may quickly pass off Pallor of the skin of the fingers leading to cyanosis and loss of the radial pulse are danger signals. Later there will be paralysis but active measures ought to have been undertaken before this has a chance to appear The treatment is the removal of all constrictive apparatus, extension of the elbow (even if the reduction of the bone fragments be jeopardized) and, if necessary exposure of the brachial artery at the elbow Ischaemic contractures of the lower limb are more often the result of external constriction. Skin tight plasters applied immediately after injury or operation cannot accommodate the post-traumatic and post-operative oedema in the space of the rigid cast.

Sudeck's post-traumatic atrophy is part of the syndrome of *causalgia* which is itself an unusual variety of post-traumatic pain. Spontaneous burning pain and stiffness of the joints, associated with arteriolar dilatation, swelling and shiny skin, comes on in a few hours or days after the injury which may have been great but is more likely to have been minor. Later the skin and nails atrophy. The condition is almost peculiar to middle aged women and old people and is confined to the hand or foot. It is a serious complication of sprained wrist or Colles's fracture and may lead to permanent loss of function. The treatment is the application of local heat by wax baths, local anæsthetic block of the cervical sympathetic ganglia, hexylmethonium bromide by intra-muscular injection or cervical sympathectomy.

(9) Neural Complications

Nerve injuries are most conveniently classified into neurapraxia, axonotmesis, and neurotmesis. Neurapraxia is a transient disturbance of conduction mostly affecting motor fibres and occurs typically in contusion, mild traction, and tourniquet paralysis. It is clinically recognizable by motor paralysis without sensory loss although often there is paræsthesia. Recovery occurs in patches in a few days or weeks and can be expected to be complete. Axonotmesis is a severing of the axons within intact endoneural tubes leading to degeneration of their distal parts but without effect on the neural architecture. During the paralysis there is complete interruption of motor and sensory function distal to the lesion, indistinguishable from that of a severed nerve but recovery tends to be complete. Exploration of healed fractures is, therefore, required if there has been no evidence of recovery of an accompanying nerve lesion. Neurotmesis is a complete interruption by severing of the nerve, by impenetrable scar tissue, intraneural injections, or ischæmia.

In the treatment of acute closed fractures and dislocations early accurate neurological diagnosis of the complicating nerve lesion is unlikely to be feasible. Neurapraxia will soon recover but exploration may be called for in order to differentiate the other two categories of nerve lesion. In the open wound the undivided nerve will be left undisturbed in the hope of spontaneous recovery of any palsy but the severed nerve will require either primary or secondary repair.

Nerve suture at the time of wound exploration is inadvisable in military surgery or in civilian accidents where there has been extensive local tissue destruction or where, for fear of sepsis, delayed primary suture of the skin has to be practised. In a fresh incised wound with clean division of the nerve, primary nerve suture is justifiable and has the advantage of the promise of early restoration of nerve function and avoids the difficulties of loss of nerve length. The epineurium is very delicate in the newly divided nerve and it may be difficult for the sutures to hold, but at least this ensures that undue tension is not applied to the nerve fragments. The digital nerves ought always to be sutured at the earliest possible occasion because they grow through quickly and surely and because complete digital function cannot be restored unless some quality of skin sensitivity is regained. All primary nerve sutures must, however, be so performed that there is no tension on the suture line when the neighbouring joints are in their optimum position for function and the bone fragments have been reduced. Apart from potential sepsis and the consequent failure of nerve repair, the arguments against primary nerve suture are two. Adequate mobilization of the nerve fragments may be difficult or

inadvisable and hence there is a temptation to relieve tension on the suture line by flexing the neighbouring joint The degree of retrograde damage of nerve stumps may not be ascertainable by inspection and a much greater degree of intraneural scarring than initially assessed may be obvious on palpation of the neuroma if a later exploration be needed. When primary suture of the nerve is not done then the stumps must be correctly orientated and approximated with stitches in the epineurium until an elective suture is performed after healing of the fracture. Although a delay of several weeks is unlikely to affect the ultimate result of nerve suture disadvantageously adverse effects are sure to be seen after a delay of 6 months after a year s interval only a poor return of function is to be expected. After 18 months to 2 years motor end plates degenerate and will never again be capable of function. Passive movements of the joints governed by the injured nerve must be given before and after nerve suture. Spring splintage to assist the normal use of the limb is a useful adjunct. Electrotherapy is of no value for the larger paralysed muscles but, started soon after injury it may be of help for the intrinsic muscles of the hand if given daily

Contusion injuries of nerves mostly undergo an uneventful recovery and so do many traction lesions after the associated fractures have been reduced. This applies to the ulnar nerve block by a supracondylar fracture of the humerus, the median nerve block by a dislocated carpal lunate and to the circumflex nerve palsy associated with dislocation of the shoulder The lateral popliteal nerve is vulnerable at the neck of the fibula to contusion, compression, and traction in knee injuries and its powers of recovery are notably less than those of other peripheral nerves. Lacerations of nerves may be sustained from sharp bone fragments and tend to occur at three sites. The median nerve may be indented by the fragments of a supracondylar fracture of the humerus the radial nerve may be caught in the groove behind the middle third of the fractured shaft of the humerus and the sciatic nerve in fracture-dislocation of the hip The last requires immediate surgery to replace and fix the acetabular fragment after reduction of the dislocation. The upper arm nerve lesions ought to be explored if no sign of recovery is apparent within 3 months of the injury

(10) Reduction

Reduction of a fracture or dislocation means restoration of the normal anatomy Sound bony union and good function are compatible with very much less than perfect reduction of fractures other than those entering into an articular surface The displaced surfaces of a joint must be restored to perfect congruity if full function of the joint is to be regained. If less than perfect reduction is to be acceptable for fractures, then standards are required against which to assess the degree of reduction achieved Apposition or contact of the fragments is essential if bony union is not to be delayed The degree of apposition is measured on the antero-posterior and lateral radiographs and expressed as a percentage of full contact (Fig. 28) Alignment really means that the long axis of each fragment must continue in one line Failing this, for the purposes of assessing reduction, correct alignment is permitted to mean that the long axes are parallel (Fig. 29) Long bones are not all straight and proper reduction must restore to each its peculiar contour

The displacements to be corrected are overlap in the oblique fracture, lateral shift with or without overlap in the transverse fracture, angulation, and rotation In the

absence of internal fixation the oblique fracture is unstable and re-displacement or secondary shortening is a constant hazard. Muscular action tends to maintain contact in the reduced fracture, unless excessive continuous traction be applied, but in fractures of the patella and olecranon, muscle action pulls the fragments apart. Interposition of muscle tissue can be a bar to reduction especially in fractures of the femoral shaft. In the forearm and leg an intact bone may hold the ends of its fractured fellow apart or prevent correct alignment. Dislocations require to be reduced as soon as possible after preliminary radiography in order to relieve pain and perhaps vascular and neural

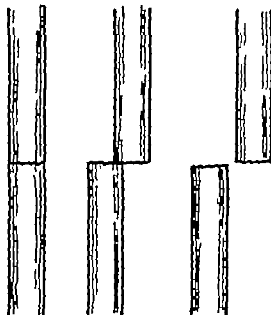


FIG. 28. Apposition.

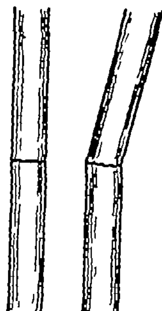


FIG. 29. Alignment.

complications. Reduction of closed fractures is not a matter of absolute urgency unless there be a risk of skin puncture by a sharp fragment of bone, of impeding the circulation, or of prolonging shock.

Reduction is usually carried out by manipulation of the fragments after abolition of muscle spasm by general anaesthesia. Pre-operative radiographs are required, not only to establish the diagnosis, but to show the degree and kind of displacement and to indicate the direction in which force must be applied in order to achieve accurate reduction. Impacted fragments will require to be disimpacted in order to correct any deformity present; this applies typically in Colles's fracture in which a combination of traction and hinging is used. Lateral displacements cannot be reduced until the overlap has first been pulled out by traction in the long axis of the bone. Correction of rotation deformities depends much more on clinical observation of the alignment of bony points on the limb than on radiography unless the whole bone can be brought into view. Although closed manipulation is quite satisfactory and preferable for the majority of fractures and dislocations there are many instances which call for open operation.

Open reduction may be required when one fragment of the fracture is difficult to

control as, for example, in the subtrochanteric fracture of the femur Fracture or turbance of an articular surface usually needs to be replaced accurately by operatio in fracture of the medial malleolus. Fracture-dislocation of the forearm (as for exar when the ulna is broken and the head of the radius is dislocated) must have the frac of one bone reduced and fixed internally in order to allow the dislocation of the o to fall into place Dislocated small bones, such as the lunate, often cannot be accur

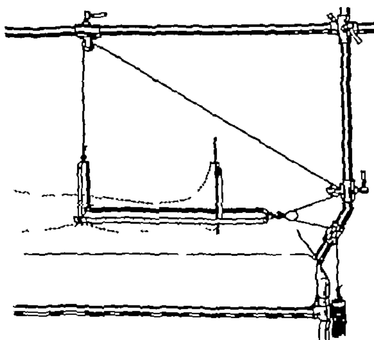


Fig. 30. Hamilton Russell traction.

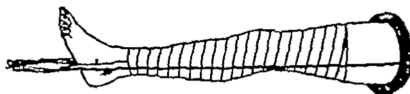


Fig. 31 Fixed skin traction in Thomas bed knee splint.

replaced without operation and the need for accurate reduction and fixation of carpals and phalanges to enable early movement of the digits may demand operation. Finally open reduction is required for fractures which have resisted c manipulation, chiefly those with lateral displacement of the fragments where over still present. Continuous traction as a method of reducing overlap of the fragmer a fractured femoral shaft has its place but it is best fixed as soon as possible be of the danger of distraction and delay in union. Continuous traction by the meth Hamilton Russell (Fig. 30) is sufficient to maintain reduction for fractures of the shaft and trochanteric region of the femur in old people and has the great advanta allowing freedom of movement and nursing is facilitated by the absence of any

in the region of the pelvis. Skin traction with the limb in a skeleton splint is a means of fixation rather than of reduction (Fig. 31)

In all fractures it is not sufficient to be content with the primary reduction and then to rely on the chosen means of immobilization for a prescribed period without further radiographic check. Secondary displacement may occur when the swelling of the limb subsides and renders the form of fixation inadequate Radiographs must be repeated at suitable intervals until sufficient union has occurred to be safe from any further displacement of the fragments.

(ii) Fixation

After reduction the fragments must be fixed until union occurs. The aims of fixation are to minimize the amount of movement of the bone ends and to maintain the fragments in position. Fractures can unite in the absence of formal splintage because muscular

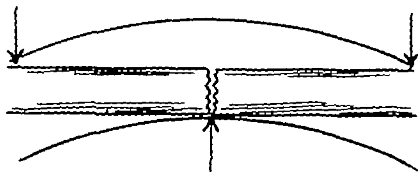


FIG. 32. Three point fixation in plaster cast.

action may be sufficient to hold the fragments in apposition or the fracture may be impacted but there is a risk of malunion and perhaps of delayed union. It is clear therefore, that movement of the bone ends is a relative matter and that absolute fixation of the fracture is not obligatory The most important function of fixation is to maintain reduction and there is a wide choice of methods for achieving this depending upon the nature and the site of the fracture.

Plaster of Paris is used in the form of a complete cast of the limb or as a fitted splint. There was a time when unpadded plaster casts were applied under the mistaken notion that a complete and accurate mould of the limb is necessary in order to hold the bone fragments. This cannot be so because the soft tissues themselves constitute padding within which the bone fragments can move. The real risk of vascular obstruction from post-traumatic and post-manipulative swelling within the rigid unpadded cast renders the method dangerous and obsolete The mechanical principle used in plaster fixation is the three point contact made by a straight rod in a curved cylinder The soft tissue connection between the reduced fragments supplies tension at the site of fracture and the fixation force is applied at each end of the plaster tube on one side and at the middle of the tube on the opposite side (Fig. 32). If the fragments cannot be held according to this mechanical principle then they cannot be held by any plaster cast, however accurately or securely moulded to the skin.

The use of traction is confined to fractures of the femur pelvis, or cervical spine except for the occasional employment of a hanging plaster cast for a long oblique

fracture of the shaft of the humerus. In fixed traction the Thomas bed knee splint is employed and the traction force is applied through the skin by using adhesive strapping or through the skeleton by transfixing the upper third of the shaft of the tibia with a Steinmann pin or Kirschner wire. Counter pressure to the traction cords is supplied by impingement of the ring of the splint on the ischial tuberosity and the discomfort from this can be relieved by slinging the splint to an overhead beam, raising the foot of the bed and counterpoising the patient by attaching a weight over a pulley to the end of the

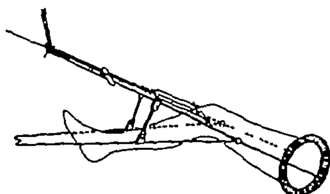


FIG. 33. Thomas splint with Pearson leg attachment.

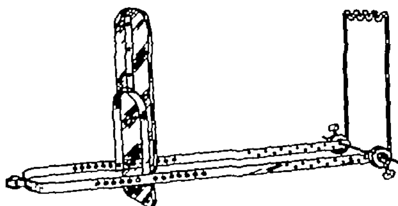


FIG. 34 Tulloch Brown splint.

splint. Continuous traction is best applied through the skeleton and the limb is slung in a cradle in the form of a Thomas bed knee splint with the Pearson attachment for the leg (Fig. 33) the Tulloch Brown splint (Fig. 34) which is admirable for the control of rotation forces, or according to the principle of Hamilton Russell (Fig. 30) The aim of continuous traction is to provide control of the fragments of the femur and yet permit early movement of the knee or to correct and maintain the reduction of fractures of the pelvis because counter pressure cannot be applied

Internal fixation is the method of choice for certain fractures. The smaller fragment may be difficult to control by any other means as in fractures of the upper third of the femoral shaft which are best fixed with an intramedullary nail. Pin and plate or nail-plate fixation of basal fractures of the femoral neck permits early ambulation and the

trifin nail is the most serviceable method of fixing the femoral head in high fractures of the femoral neck. Screw fixation of the fractured medial malleolus is necessary to reconstruct the mortise of the ankle joint. Similarly diastasis of the inferior tibio-fibular joint calls for bolting of the two bones together. Loss of the power of rotation in the forearm is so great a disability that plating of the fractured radius and ulna is advisable in order to avoid it. Two fractures of one bone or multiple fractures of one limb will often benefit by the use of internal fixation of one or some of the fractures in order to make the treatment of the others feasible. Unstable fractures of subcutaneous bones such as the tibia need fixation with screw or even a plate. In fractures of the femur the use of plates greatly increases the chance of stiffness of the knee and it is better to perform an open reduction whilst the limb is fixed on the splint and omit any form of internal fixation.

(12) Rehabilitation

This is a continuous active process beginning with first aid immediately after the injury has been sustained and it is not a phase of treatment to be started after the fracture has healed. Rehabilitation consists of mobilizing the patient physically and mentally to regain full, active movement in all parts other than the immobilized fragments of the fractured bone. It is often a matter of urgency, especially in the hand, where loss of time in mobilizing fingers and of dispelling œdema after an injury can mean permanent stiffness of the fingers and irremediable loss of function. The restoration of movement in joints which have been allowed to go stiff means pain and avoidable delay and perhaps some degree of permanent restriction of movement that need never have occurred. Manipulation by the surgeon and passive movements by the physiotherapist are not adequate substitutes for the natural evolution of movement that only the patient is capable of regaining under instruction. The whole aim of rehabilitation is occupational therapy in the widest sense of the term and at its best that means employment at suitable work in industry or the home. In enlightened parts of the country many men are returned to employment whilst they are still wearing plasters and other apparatus. When injuries are such that return to pre-accident work is not possible then the Disablement Resettlement Officer has an important role to fill in settling the patient into industry again. In the heavy forms of industry, such as coal mining, provision is made by their welfare services for rehabilitation at residential centres. Segregation of patients for convalescence is not so satisfactory in civil life as it was for the reablement of men for fighting units during the war. Such centres have a tendency now to prolong convalescence and to foster invalidism. The residential centres must offer graduated physical endeavour until the patient is fit to face the heaviest labour. Alternatively training in suitable occupations of a lighter nature must be supplied in appropriate training establishments.

IV

TREATMENT OF INDIVIDUAL FRACTURES AND DISLOCATIONS

(13) Shoulder Girdle

(a) Dislocation of Sterno-clavicular Joint. The displacement of the sternal end of the clavicle is usually forwards and upwards from a downward force on the point of the shoulder which levers the clavicle over the first rib. A lump is felt over the

joint which is tender especially during arm movements The displacement is readily reduced by bracing the patient's shoulders back but redislocation is equally easy A figure of eight bandage, reapplied daily is used for a fortnight and the arm is left free to move. An unreduced dislocation is rarely a disability but women must be warned that a permanent lump will be visible at the joint. The very rare posterior dislocation of the sterno-clavicular joint is associated with fractures of the upper ribs and respiratory distress. Reduction is done by pressing back the shoulders over a sandbag whilst the patient is lying supine and the reduction is stable.

(*b*) Fracture of the Shaft of the Clavicle. A transverse fracture in the middle of the bone is the most common fracture and there is often a loose third fragment. The fracture is caused by a fall on to the outstretched hand or on to the point of the shoulder which forces the clavicle upwards and backwards The inner fragment of the clavicle is elevated by the sterno-mastoid and the outer fragment drops down because of the weight of the arm. The fragments are reduced by pulling back the shoulders and the position is maintained by applying a figure of eight bandage over large axillary pads The bandage pulls the outer half of the bone upwards and backwards and the pressure of the arm on the axillary pad gives traction in the long axis of the clavicle. The bandage must be reapplied daily for a fortnight but the arms ought to be left free from the beginning and active movements are encouraged. Union nearly always occurs but some visible and palpable swelling at the fracture site will be permanent.

(*c*) Fracture of the Outer End of the Clavicle. This fracture is the result of a fall or of a blow direct on to the top of the shoulder The commoner line of fracture lies lateral to the conoid and trapezoid ligaments and consequently there is very little displacement of the fragments and only a little local tenderness no treatment is required except to encourage active movements of the shoulder Alternatively the line of fracture is medial to the conoid and trapezoid ligaments and the inner fragment of the clavicle is displaced upwards and backwards to form a palpable lump. The condition is treated as for an acromio-clavicular dislocation and union usually occurs in 6 weeks.

(*d*) Acromio-clavicular Dislocation This injury is caused by a direct blow on the point of the shoulder If only the acromio-clavicular ligaments are torn there is then a slight degree of upward displacement of the outer end of the clavicle constituting a subluxation of the joint. If the conoid and trapezoid ligaments are also torn then the acromio-clavicular joint is dislocated and the upward displacement of the outer end of the clavicle is plainly visible. Reduction of the displacement by elevation of the arm and pressure over the clavicle is easy but more difficult to maintain. The best method of fixation is to use a webbing strap and buckle fastened tightly over a pad on the clavicle and one under the flexed elbow an additional webbing strap is attached to the first round the chest under the opposite axilla, which prevents the first strap from slipping and when tightened increases the compression exerted by the first strap (Fig. 35) The apparatus is worn for 6 weeks

(*e*) Fractures of the Scapula. Fracture of the body of the scapula is caused by a direct blow There is no displacement, the tenderness rapidly settles and active movements of the arm ought to begin straight away Fracture of the neck of the scapula occurs after a direct blow on the shoulder and the line of fracture runs from the supra scapular notch to just below the glenoid cavity The weight of the arm displaces the outer fragment downwards. The shoulder swells and clinically resembles a dislocated shoulder

but is differentiated by radiography After the arm has rested in a sling until the pain subsides active shoulder movements are started and the fracture is disregarded.

(14) Shoulder

(a) FORWARD DISLOCATION This is a common injury in adults up to middle age. It is produced by a fall on to the outstretched hand or on to the elbow when it is behind the trunk. Any fall or blow which will cause a thrust of the humeral head on to the

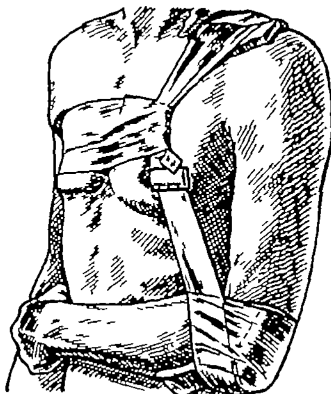


FIG. 35. Apparatus for acromio-clavicular dislocation.

front of the capsule and the glenoid ligament may avulse their attachments to the edge of the glenoid cavity and so permit the humeral head to travel forwards and upwards to lie under the coracoid process (Fig. 24) A continuation of the same force causes the head of the humerus to shift upwards under the clavicle where it may press on the underlying vessels and nerves. Occasionally as when falling down a well or from a height, the *luxatio erecta* occurs in which the arm is locked erect with the humeral head under the rim of the glenoid cavity (Fig. 36) The commonest complication of any dislocation of the shoulder is paralysis of the deltoid muscle as a result of compression on or traction of the circumflex nerve. Not infrequently in severe dislocations the concomitant traction on the brachial plexus causes other nerve lesions in the upper limb.

The dislocation is easily overlooked because of the local swelling, which may conceal the displaced humeral head, or because it occurred during a fit. In a thin person flattening

of the shoulder contour beneath the deltoid with prominence of the acromion may be visible. All movements of the dislocated shoulder joint are restricted and painful The arm appears to be longer than its fellow and the elbow cannot touch the side of the body

Reduction ought always to be performed under anæsthesia after a radiograph has been taken to make sure that there is no complicating fracture The best method of reduction is that of Hippocrates. The surgeon's stockinged foot is placed in the patient's axilla and the operator exerts traction in the long axis of the arm by grasping the wrist the humeral head will retrace its steps into the joint. Only occasionally will supplementary pressure be required upwards or backwards directly on the humeral head

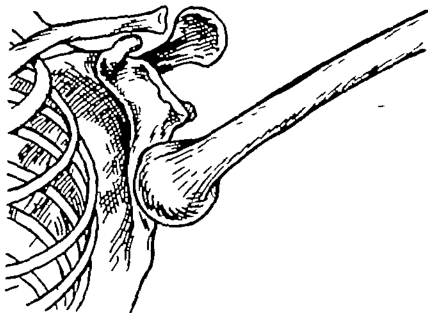


FIG. 34. *Luxatio erecta* of the shoulder

When reduction has been achieved active abduction must be tested to see if there has been any tearing of the supraspinatus tendon If the supraspinatus be intact then, in a young adult, it is best to maintain the position of internal rotation of the shoulder for 3 weeks to allow healing of the capsule in the attempt to avoid the tiresome sequela of recurrent dislocation. In the old person recurrent dislocation is almost unknown and early activity is encouraged without fear of any untoward late complication. If the supraspinatus tendon has been ruptured then exploration and repair is needed. There is no danger of causing permanent stiffness of the shoulder in young adults by immobilization. Abduction of the arm is not required for deltoid paralysis because the position of relaxation for this muscle is with the arm down by the side.

(*b*) BACKWARD DISLOCATION This dislocation is very rare and is caused by a direct blow on the front of the shoulder or by forced internal rotation of the arm. The head of the humerus lies behind the glenoid rim under the spine of the scapula and the posterior capsule and glenoid labrum are torn. The injury is usually overlooked because clinically it is difficult to diagnose. No apparent alteration of the contour of the shoulder may be

visible and the ordinary antero-posterior radiograph of the shoulder does not clearly show the displacement. The surest clinical sign of the dislocation is prominence of the acromion. A radiograph taken by vertical projection down on to a curved cassette in the axilla readily demonstrates the posterior displacement of the humeral head. Reduction is obtained by traction on the arm and external rotation and then the arm is immobilized for 3 weeks to allow the capsule to heal.

(c) UNREDUCED DISLOCATIONS. A dislocation of the shoulder can be easily overlooked and a relatively small disability may result. If the dislocation has been present for longer than 6 weeks in older people and reduction is not easily obtained by manipulation the dislocation is best accepted. In very forcible manipulation of such shoulders there is always the risk of fracturing the humerus, of causing a traumatic aneurysm of the axillary artery or a brachial plexus traction lesion.

(d) FRACTURE OF THE GREATER TUBEROSITY OF THE HUMERUS. These fractures may occur as a result of a direct blow but mostly they are in association with a dislocation of the shoulder or a fracture of the neck of the humerus. The greater tuberosity is driven against the upper rim of the glenoid cavity when the arm is abducted, and it is contused. The tuberosity or a triangular piece of bone is broken off but rarely is there any displacement. No treatment is required except active movements. The tuberosity may also be avulsed at the time of dislocation of the shoulder and the mechanism is that of the torn supraspinatus tendon. It occurs when the humerus is undergoing forcible internal rotation. There may be no displacement of the bone fragment (in which event no treatment is required) or the fragment may be pulled up under the acromion and the patient will be unable actively to abduct the arm. Open reduction of the fragment and fixation with sutures is recommended in order to avoid shoulder stiffness from prolonged immobilization.

(e) FRACTURE-DISLOCATION OF THE SHOULDER. This is always a very serious injury which may cause complete separation of the humeral head at the time of the accident. Without a preliminary radiograph to show what degree of separation of the fragments of the fracture is present, it is possible by blind manipulation to fail to reduce the dislocation of the shoulder joint and instead to complete the separation of the humeral head from the distal fragment. Complete separation of the humeral head will cause much pain and swelling of the shoulder and the free head will come to lie on the floor of the axilla and may cause vascular and neural complications. Closed reduction is possible but usually unsatisfactory and, if successful, will require that the arm be fixed in abduction. Unless the humeral head can be accurately returned to the socket open reduction is indicated although further damage to the blood supply of the capital fragment will occur and there will be grave risk of later avascular necrosis. The displaced humeral head must not be excised, except in very old people, because of the poor function which will result.

(15) Arm

(a) FRACTURE OF THE NECK OF THE HUMERUS. These fractures commonly occur in middle-aged women as a result of a fall on to the outstretched hand. Nearly all these fractures are high, transverse, and impacted and the relationship of the shaft of the humerus to the head of the bone differs according to the direction in which the trunk falls after the hand has become fixed on the ground. In the adduction fracture the

impaction is on the inner half of the fracture and the shaft is adducted in relation to the humeral head. In the abduction fracture the shaft is abducted in relation to the humeral head and the impaction is on the outer half of the fracture

The symptoms are usually mild and are related to a definite fall but the patient may not seek medical advice for a few days or weeks. The shoulder is bruised and tender and attempted movements are painful. It may be possible to correct the angulation by leverage of the arm in manipulation but it is unwise because of the danger of disimpaction of the fragments. No accurate reduction is required and the arm needs only to be rested in a sling for a few days to allow the pain to subside Active movements of the shoulder are to be encouraged at the earliest possible time but passive movement may cause movement at the fracture site and so delay union. Even the severe type of abduction fracture, in which the range of movement at the joint can never be great because the humeral head is not congruous with its socket, is best treated conservatively because the patients are older people. Arthroplasty and the substitution of an acrylic prosthesis has proved to be unsatisfactory Function so far as the patient is concerned is, as a rule, better than the actual restricted range of passive movement at the shoulder joint would suggest and rarely amounts to a notional disability In a young man open reduction of a severe abduction fracture may be considered but the danger of subsequent avascular necrosis is always to be borne in mind.

Occasionally a non-impacted fracture of the humeral neck occurs in young people. The upper fragment will be abducted by the spinatus muscles and the lower fragment will be drawn upwards and inwards by the pectoralis major biceps, and coraco-brachialis muscles. The fragments must be made to hitch on to one another by abducting and pulling the arm and then the arm is returned to the side and kept in a sling for about 10 days. In none of the fractures of the neck of the humerus is an abduction splint permitted because the position may allow malunion to take place in abduction at the fracture site the consequent inability to bring the arm down to the side of the body may call for corrective osteotomy Fracture separation of the capital epiphysis of the humerus is uncommon but it has always to be recalled when a child (up to adolescence) sustains an injury to the shoulder by falling on to the outstretched hand. No correction of the displacement is required and the arm is best treated in an abduction splint for 3 weeks. Function returns to normal and any residual angulation tends to be masked during later growth.

(*b*) Fractures of the Shaft of the Humerus. Most of these fractures are spiral from rotational stress and they occur at the junction of the middle and lower thirds of the bone. Some fractures are transverse at the middle of the shaft as a result of an angulating force. The arm is not apparently deformed but it cannot be used because of pain at the fracture site and it is supported in the other hand. The patient may be conscious of crepitus when he moves the fractured bone. The displacement of the fragments is very little because of the relative weakness of the muscles of the upper arm and of the effect of gravity Absolute fixation of the fragments is not necessary for the majority of these fractures A plaster U slab from the axilla round the elbow up to the shoulder is usually all that is required except that the forearm is supported in a sling. The spiral fractures heal easily in about 5 weeks. Sometimes there is trouble with the transverse fracture especially if the patient is an obese woman, because of the difficulty of avoiding angulation. In such a situation the upper fragment will become abducted

and the lower fragment of the humerus must be brought into line with the upper fragment, and hitched on so that immobilization in a U slab can be given. The use of a shoulder spica to maintain the arm in abduction tends to allow the elbow slowly to sag and for worse angulation to occur than by bringing the reduced fragments down to the side initially No continuous traction is required for any of the humeral fractures and the only danger of delayed union is from distraction of the fragments even from just the effect of gravity Radial nerve palsy is a likely complication of the transverse fracture but it usually recovers. In the interval spring splintage for the hand (Brian Thomas) (Fig. 37) is required. After union of the fracture, if the radial palsy should have persisted, *it will be necessary to decide whether the nerve is to be explored and sutured or whether* to proceed directly to tendon transposition in the forearm When non union of the fracture does occur it is difficult to treat but after freshening of the bone ends at the

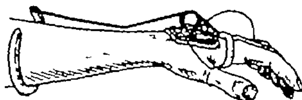


FIG. 37 Brian Thomas splint for radial palsy

fracture site the fragments will require fixation either by means of an intramedullary nail or by plate and screws with the addition of cancellous bone chips at the fracture site.

(16) Elbow

The epiphysial injuries are necessarily peculiar to the growth period. Although most *of the other elbow lesions can occur at any age there is naturally a tendency for age to* be a selective factor

Adults

(*a*) INTERCONDYLAR FRACTURE OF THE HUMERUS. This fracture is caused by a fall on to the flexed elbow The olecranon is driven up between the humeral condyles, splits them and the line of fracture passes upwards and forwards to separate the condyles from the shaft (Fig. 38) In the obese middle-aged woman the lower end of the humerus may be shattered *and the elbow converted into a crepitating bag of bones. The elbow* rapidly swells and bony points are difficult to feel. Accurate reposition of the fragments is only possible by open operation but this is to be avoided because the improvement in the radiographic appearance is with difficulty achieved at the price of a stiff elbow For the grossly comminuted fracture a collar and cuff sling is all that is required. Gravity is used for the reducing force and the fragments will unite in 5 weeks. After 3 weeks, active movements of the elbow with the arm in a sling are encouraged. No massage or passive movement for *any* elbow lesion is ever allowed at *any* time if joint stiffness is to be avoided or reduced to a minimum. The elbow is an "irritable" joint which stiffens permanently if forcibly driven but will often react favourably to being coaxed. *For the T-shaped fracture the best method is to screw* the humeral condyles together through a limited medial or lateral exposure and so convert the composite fracture into a plain supracondylar fracture and to ensure that the humeral articular

face is restored. Manipulative reduction of the supracondylar component and fixation posterior plaster splint and sling gives union in 5 weeks active movements of the elbow with the arm in a sling can be started after 3 weeks.

(b) FRACTURE OF THE OLECRANON. This fracture occurs when the elbow is suddenly forcibly flexed as in a fall and the triceps avulses the bone The fracture is usually transverse at the middle of the olecranon fossa. There is swelling of the elbow tenderness over the fracture and often a palpable gap Sometimes there is forward dislocation of the elbow which will require manipulative reduction before fixing the loose fragment

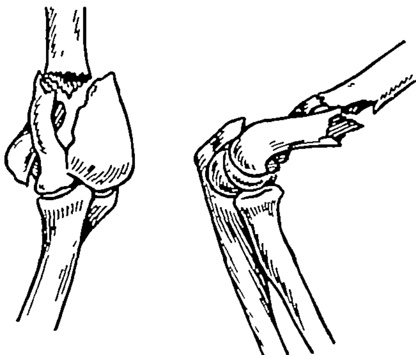


FIG. 38. Intercondylar fracture of the humerus.

and it is a contra-indication to excision of the olecranon The reason for reducing the fracture accurately is to restore the power and action of the triceps. Open reduction and fixation is required, except in extreme old age or very bad general health The avulsed fragment is fixed with catgut sutures or more securely with an intramedullary screw In old people excision of the olecranon and suture of the triceps to the ulna is a satisfactory procedure and this requires the arm to be immobilized a little short of full extension for 2 weeks. After fixing the olecranon the arm is kept in a sling for 3 weeks at a right angle and then active movements of the elbow may be started.

(c) FRACTURE OF THE CAPITELLUM This fracture is produced by the reactionary force of falling on to the outstretched hand travelling up the radius and delivering a shearing blow on the front of the capitellum (Fig. 39). There may be an associated fracture of the head of the radius. The size of the fragment of the capitellum will depend upon the angle at which the radial head strikes it. The fragment may be a small flake or the whole of the anterior half of the capitellum and it is displaced into the joint as a loose body unless it is so small as to consist of only a sliver of articular cartilage. The elbow

will be only slightly swollen and held at a right angle but apparently not otherwise abnormal. A full range of rotation will be present but flexion of the elbow will be reduced to a few degrees. The fragment may be manipulated downwards whilst the elbow is extended, held in position with the operator's thumb as the elbow is flexed. Reduction is maintained by the head of the radius if the elbow is kept fully flexed for 2 weeks. When operative treatment is required small fragments of cartilage, if backed with only a flake of bone, are best removed because they are likely to die if restored to their former site.



FIG. 39 Fracture of the capitellum.

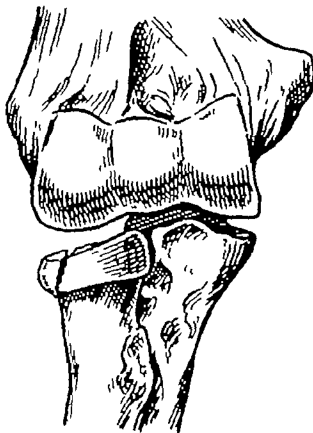


FIG 40. Marginal fracture of the head of the radius.

The larger fragments must be reduced because they still retain a blood supply if their soft tissue attachments are carefully preserved. Once the fragment is restored to its bed it is likely to remain in place. The arm is immobilized with the elbow at a right angle in a sling for 3 weeks but active movements in the sling may begin within a few days.

(*d*) FRACTURE OF THE HEAD OF THE RADIUS. These fractures are all caused by falling on to the outstretched hand and so forcing the elbow joint into valgus. The fracture of the radial head is the only radiographically visible part of the composite injury which includes the radial head, capitellum, and the soft tissues of the medial aspect of the elbow joint. It is for this reason that the commonest sequela of the fracture of the head of the radius is restriction of extension of the elbow. The fracture may show in the radiograph as a crack, a marginal fracture (Fig. 40) or a comminuted fracture. Clinically there may

be tenderness localized to the head of the radius, some restriction of rotation in the less severe injuries but in the more gross there will be much restriction of movement and pain during valgus stress. The treatment for most of these injuries is operative for the removal of the whole of the radial head. Excision of the marginal fragment is not enough and the use of an internal prosthesis is not indicated. Only the crack fractures without any depression of the radial articular surface may be safely left and even in these the prognosis depends on the occult damage. Active movements of the elbow are permitted whilst the arm is in a sling but even in favourable circumstances, full function of the elbow is not to be expected for at least 3 months. Any attempt to hurry it will only cause more limitation of elbow extension. Not infrequently heterotopic ossification occurs in the torn joint capsule and will further delay recovery of function. The decision to excise the head of the radius must be made within 4 weeks of the injury and the earlier the better because late excision rarely gives any material improvement of restricted elbow movement.

(e) Dislocation of the Elbow. This is a common injury usually from a fall on to the outstretched hand. Both forearm bones are displaced backwards on the humerus and also either medially or laterally; the brachialis muscle is avulsed from the coronoid process of the ulna or the process is fractured. From the nature of the mechanism of the injury it is to be expected that the dislocation is not infrequently complicated by fracture of the radial head, capitellum, condyles, or epicondyles of the humerus. Clinically the condition is diagnosed by noting the posterior outline of the elbow where usually the projecting olecranon can be felt as a knob. Vascular complications must always be borne in mind at the preliminary examination and the danger of them is a potent reason for early reduction of the dislocation. A preliminary radiograph is essential to determine whether there are any associated fractures. Manipulation under anæsthesia consists of traction on the forearm in the position in which it is lying and, in the absence of any complicating fracture, no other manœuvre ought to be necessary. Full extension of the elbow during reduction is to be avoided because of the danger of irritating the brachial artery. A post-operative radiograph is required to check that the sideward displacement is also fully corrected and that a fractured medial epicondyle is not included in the joint. The arm is immobilized in a collar and cuff sling for 3 weeks with a *plaster strip* moulded down the back of the arm to obviate any recurrence of medial displacement. Only active movements are allowed after the period of immobilization and any attempt to do more is likely to increase the disability and to favour the deposition of heterotopic ossification in the capsule of the joint and the brachialis. The prevalence of the odd habit of driving a car with an elbow stuck out through the window is responsible for the appearance of a vicious fracture-dislocation of the elbow in which the dislocation is complicated by a comminuted fracture of the olecranon, a *forward shift of the forearm* and fractures of the ulna and humeral shafts. The forward dislocation must immediately be reduced and the fractures can be dealt with at a later date. The functional result of such a comprehensive injury is likely to be so poor that reconstructive surgery will ultimately be required.

Children

(a) Supracondylar Fracture of the Humerus. This is the commonest injury of the elbow in a child and it is caused by a fall on to the hand. The fracture is across the

will be only slightly swollen and held at a right angle but apparently not otherwise abnormal. A full range of rotation will be present but flexion of the elbow will be reduced to a few degrees. The fragment may be manipulated downwards whilst the elbow is extended, held in position with the operator's thumb as the elbow is flexed. Reduction is maintained by the head of the radius if the elbow is kept fully flexed for 2 weeks. When operative treatment is required small fragments of cartilage if backed with only a flake of bone are best removed because they are likely to die if restored to their former site.

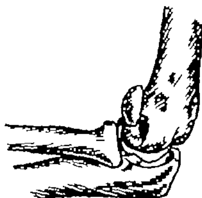


FIG. 39 Fracture of the capitellum

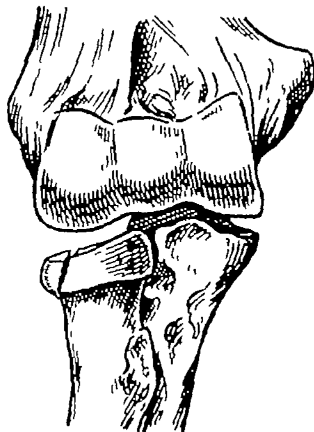


FIG. 40. Marginal fracture of the head of the radius

The larger fragments must be reduced because they still retain a blood supply if their soft tissue attachments are carefully preserved. Once the fragment is restored to its bed it is likely to remain in place. The arm is immobilized with the elbow at a right angle in a sling for 3 weeks but active movements in the sling may begin within a few days.

(*d*) FRACTURE OF THE HEAD OF THE RADIUS. These fractures are all caused by falling on to the outstretched hand and so *forcing the elbow joint into valgus*. The fracture of the radial head is the only radiographically visible part of the composite injury which includes the radial head, capitellum, and the soft tissues of the medial aspect of the elbow joint. It is for this reason that the commonest sequela of the fracture of the head of the radius is restriction of extension of the elbow. The fracture may show in the radiograph as a crack, a marginal fracture (Fig. 40) or a comminuted fracture. Clinically there may

be tenderness localized to the head of the radius, some restriction of rotation in the less severe injuries but in the more gross there will be much restriction of movement and pain during valgus stress. The treatment for most of these injuries is operative for the removal of the whole of the radial head. Excision of the marginal fragment is not enough and the use of an internal prosthesis is not indicated. Only the crack fractures without any depression of the radial articular surface may be safely left and even in these the prognosis depends on the occult damage. Active movements of the elbow are permitted whilst the arm is in a sling but, even in favourable circumstances, full function of the elbow is not to be expected for at least 3 months. Any attempt to hurry it will only cause more limitation of elbow extension. Not infrequently heterotopic ossification occurs in the torn joint capsule and will further delay recovery of function. The decision to excise the head of the radius must be made within 4 weeks of the injury and the earlier the better because late excision rarely gives any material improvement of restricted elbow movement.

(*e*) DISLOCATION OF THE ELBOW. This is a common injury usually from a fall on to the outstretched hand. Both forearm bones are displaced backwards on the humerus and also either medially or laterally; the brachialis muscle is avulsed from the coronoid process of the ulna or the process is fractured. From the nature of the mechanism of the injury it is to be expected that the dislocation is not infrequently complicated by fracture of the radial head, capitellum, condyles, or epicondyles of the humerus. Clinically the condition is diagnosed by noting the posterior outline of the elbow where usually the projecting olecranon can be felt as a knob. Vascular complications must always be borne in mind at the preliminary examination and the danger of them is a potent reason for early reduction of the dislocation. A preliminary radiograph is essential to determine whether there are any associated fractures. Manipulation under anæsthesia consists of traction on the forearm in the position in which it is lying and, in the absence of any complicating fracture, no other manœuvre ought to be necessary. Full extension of the elbow during reduction is to be avoided because of the danger of irritating the brachial artery. A post-operative radiograph is required to check that the sideward displacement is also fully corrected and that a fractured medial epicondyle is not included in the joint. The arm is immobilized in a collar and cuff sling for 3 weeks with a plaster strip moulded down the back of the arm to obviate any recurrence of medial displacement. Only active movements are allowed after the period of immobilization and any attempt to do more is likely to increase the disability and to favour the deposition of heterotopic ossification in the capsule of the joint and the brachialis. The prevalence of the odd habit of driving a car with an elbow stuck out through the window is responsible for the appearance of a vicious fracture-dislocation of the elbow in which the dislocation is complicated by a comminuted fracture of the olecranon, a forward shift of the forearm and fractures of the ulna and humeral shafts. The forward dislocation must immediately be reduced and the fractures can be dealt with at a later date. The functional result of such a comprehensive injury is likely to be so poor that reconstructive surgery will ultimately be required.

Children

(*a*) SUPRACONDYLAR FRACTURE OF THE HUMERUS. This is the commonest injury of the elbow in a child and it is caused by a fall *on to the hand*. The fracture is across the

humerus immediately above the epiphysial line and the lower fragment, carrying with it the forearm, is displaced backwards and upwards and usually there is also a sideways shift (Fig. 41). The line of fracture is oblique upwards and backwards from the front of the bone. The elbow is swollen and painful and the child is fearful of anyone touching the arm. A pre-operative radiograph is required and is best taken after the anæsthetic has been administered and then the manipulation can proceed. An accurate reduction is required even if more than one manipulation is needed to achieve it. Failure to correct the forward tilt of the lower fragment will restrict extension of the elbow because of premature locking of the olecranon in its fossa. A persistent backward tilt of the lower fragment will cause restriction of elbow flexion and uncorrected sideways displacement or tilt will produce cubitus valgus or varus. The belief that inaccuracies of the reduction will be ironed out later during the growth period is erroneous. The essential element in manipulation is traction on the arm which must be maintained during the flexion of the elbow which is to hitch the fragments on to one another. The line of fracture ensures that after reduction the fragments will be stable when the arm is in flexion. It is unwise to fix the elbow above half flexion because of the danger of embarrassment of the circulation. This fracture is the commonest cause of Volkmann's contracture (Fig. 27) and constant watch is required for the first 48 hours after injury for signs of arterial obstruction. After reduction a plaster strip is moulded down over the back of the arm to make sure that medial displacement of the lower fragment does not recur and the arm is slung in a collar and cuff sling for 3 weeks. After removal of the sling the child is best left to gain his own elbow movement and physical treatment and the temptation to force movement must be avoided. Supracondylar fracture with forward displacement of the lower fragment is a rare condition and it is caused by a fall on to the elbow. The site of fracture is similar to that of the former fracture but the oblique line of fracture is upwards and forwards from the back of the bone. Stability of the fragments after reduction can only be assured, therefore, when the arm is fixed in extension. Reduction is readily performed by traction and extension of the arm and adjustment of the carrying angle. Fixation by posterior plaster strip and bandage with the arm in extension is required for 2 weeks and then the elbow is coaxed into flexion. The position of immobilization is awkward and undesirable because it encourages œdema of the hand and a tendency to stiff fingers if the arm is permitted to hang down for more than short periods at a time.

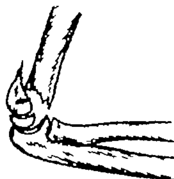


FIG. 41 Supracondylar fracture of the humerus.

(b) FRACTURE OF THE LATERAL CONDYLE OF THE HUMERUS. This fracture is not common but it is the likeliest injury to be confused with a supracondylar fracture. It is caused by a fall on to the outstretched hand and the force transmitted up the radius knocks off the whole lateral condyle. If there be any displacement then the lower fragment, by reason of the attachment of the extensor muscle group of the forearm is laterally rotated on its horizontal and vertical axes so that the fracture surface faces out of the joint. Accurate reposition of the fragment in its bed is essential if later cubitus valgus and delayed ulnar palsy are not to occur. Although it is sometimes possible to

reduce the fragment by manipulation it is best to proceed directly to open operation so that the fragment can be accurately replaced The tendency to non-union is best countered by fixation of the fragment with a screw

(*c*) FRACTURE OF THE MEDIAL EPICONDYLE OF THE HUMERUS. This injury is really an avulsion of the epiphysis of the medial epicondyle and can only occur in adolescents during the period when the epiphysis exists as a separate entity The injury is caused by a fall on to the outstretched hand which forces the elbow into valgus and so stretches the flexor muscle group of the forearm which is attached to the epicondyle (Fig. 42) The elbow is painful but as a rule little disturbed but there is usually some swelling and tenderness over the medial aspect of the joint Radiographs are essential to determine the degree of separation of the epiphysis which is also a measure of the degree of injury to the joint capsule. If the fragment is only pulled down then resting the arm in a sling is all that is required because the muscle origin fixes in the new position without losing any of its strength. Full recovery of extension of the elbow is a matter of months but only active movements by the patient are allowed. If the valgus stress on the elbow has been great enough to tear the medial part of the capsule then the joint will open out and the epiphysis may be included in the joint as it snaps back into position. In a recent inclusion it is usually possible to extricate the fragment under anaesthesia by forcing the joint into abduction and stimulating the flexor group of forearm muscles with faradism. When open operation is required the flexor muscles can easily be hooked out of the joint and the epiphysis be stitched back into position. In these injuries the ulnar nerve is always bruised but never divided and any palsy is temporary and will usually recover It is advisable, however to perform an anterior transposition of the nerve so that it will be out of its former groove which will become thickened and irregular and may cause delayed ulnar palsy



FIG. 42. Fracture of the medial epicondyle of the humerus.

(*d*) FRACTURE OF THE NECK OF THE RADIUS. This is a common injury in young children. It is a greenstick fracture of the neck of the radius caused by a fall on to the hand which produces a valgus strain in the elbow and tilting of the radial head outwards. It is essential to reduce the displacement of the radial head because growth in the deformed position would lead to subluxation or even dislocation of the radial head. The child will complain of pain in the elbow and resent clinical examination and without radiography the injury can easily be dismissed as a "pulled elbow" The radiograph reveals the deformity of the radial neck and the absence of the epiphysial line which is obscured by the overlying radial head. It is sometimes possible to correct the displacement by manipulation but it is difficult to correct it fully Open operation is usually required and then the radial head can easily be pressed into position and no form of fixation is required Excision of the radial head in a child must never be done because it is always unnecessary and it carries the late complication of subluxation of the inferior radio-ulnar joint because the ulna grows faster than the beheaded radius. "Pulled Elbow" is caused by an impatient parental tug on the child's arm which causes the radial head to be pulled out of its orbicular ligament. The condition is

treated by alternately pronating and supinating the forearm and no anæsthesia is required.

(17) Forearm

(a) FRACTURE OF THE SHAFT OF THE RADIUS AND ULNA. These fractures are common in adults and children and they are caused by a fall on to the hand. In children the fractures are usually greenstick and they can often be manipulated without conversion into complete fractures with displacement consequently they heal in 8 weeks without any residual disability

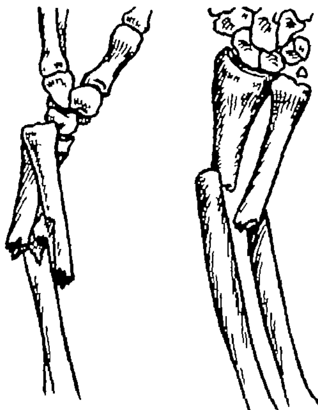


FIG. 43 Fracture of the radius and ulna.

The problems of the management of complete separation of the bone fragments are the correction of the rotational and angular deformities of both bones simultaneously and of their efficient fixation so as to prevent secondary displacement. Absolutely accurate reduction in both bones is essential if the radio-ulnar joints are to work correctly otherwise there is bound to be some residual restriction of rotation in the forearm. Even a minor degree of diminished power and range of rotation in the forearm is a real disability especially in the execution of fine movements of the hand. The rotation deformity to be corrected is often extreme because in fracture of the radius at the junction of the upper and middle thirds the upper fragment is fully supinated by the biceps and the supinator muscles and the lower fragment is fully pronated by the pronator teres and

pronator quadratus muscles. Even when the fracture of the radius is below the mid point of its shaft the rotational deformity will still tend to be about 90 degrees because the upper fragment is held in mid position by the balanced action of the supinators and pronator teres and the lower fragment is fully pronated by pronator quadratus (Fig. 43) The angulation deformities depend upon the degree of unspent force after the bones have fractured. Clinically the diagnosis is usually clear because of the obvious deformity of the forearm

Reduction for overlap fractures of the radius and ulna in children is performed by manipulation to preserve and make use of the hinge of intact periosteum on the concave



FIG. 44. Reduction of fracture of the radius and ulna by manipulation.

side of the fracture (Fig. 44) A curved plaster cylinder is applied to maintain three point fixation (Fig. 32) and the plaster extends from axilla to the metacarpal heads. Apposition of the bone ends is essential for union to take place and the correction of rotation deformity must be judged on a radiograph taken with the forearm in full supination so that the bones will be in line with their proximal fragments and the correct width of interosseous space will be visible It is usually possible to reduce the fragments satisfactorily in children by this method but if reduction is not satisfactory then open reduction without internal fixation is advisable and then the bones are fixed in plaster as for closed reduction.

The method of closed manipulation is frequently employed for adults but the quality of reduction tends to be less than the absolute criterion demanded to ensure the restoration of full function. Moreover plaster immobilization cannot be relied upon to prevent displacement of the fragments and what has been accepted as satisfactory reduction may have to be re-manipulated with every possibility of an inferior quality of reduction as a result. In addition all failed closed manipulations have to be corrected by open operation For these reasons it is rightly advocated that open reduction of both forearm bones be done and that the fragments be fixed with plates and screws (Fig. 45) The argument for this decision is not to achieve quicker union but to be certain that reduction of the fractures is accurate and will remain so until union occurs. In order to be certain that union will occur plaster immobilization of the arm from axilla to knuckles with the forearm in the mid position must also be used but not immediately after the operation. The integrity of the internal fixation can be relied upon for at least a month and then

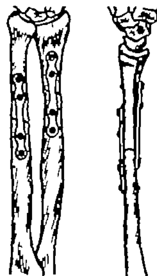


FIG. 45 Internal fixation of fracture of the radius and ulna

rotational stresses tend to loosen screws and to promote movement of the bone ends and so delay union. *But by this time the forearm ought to have regained a good range of movement, the wounds will be healed, all œdema will have been dispelled and the limb will be virtually normal in function.* Such an arm when placed in plaster will not be subject to the stiffness that initial plaster immobilization may cause and the plaster can be made to fit accurately without danger of swelling and vascular obstruction. Whatever line of treatment is adopted for overlapping fractures of both bones the minimum period required for certainty of union will be 3 months.

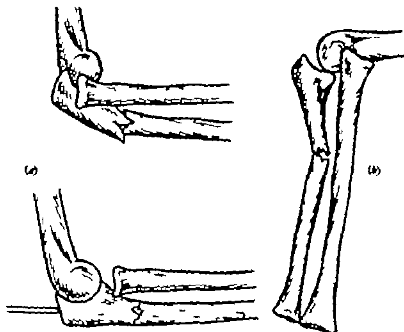


FIG. 46. ( ) Anterior and (b) posterior Monteggia fracture-dislocation with fixation.

(*b*) FRACTURE DISLOCATION OF THE FOREARM. The fracture of one forearm bone with displacement or angulation of the fragments must mean a subluxation or dislocation of the neighbouring joint. So long as the companion bone remains intact, angulation of the fractured bone can only take place at the expense of the nearest joint. The two common fracture-dislocations of the forearm are fracture of the upper third of the ulna with dislocation of the head of the radius (Monteggia) and fracture of the lower third of the radius with dislocation of the lower radio-ulnar joint (Galeazzi).

The Monteggia fracture-dislocation is a common lesion mostly caused by a direct fall on to the ulna to yield a transverse fracture of the upper third of the shaft of the bone and a forward dislocation of the radial head (Fig. 46) There is anterior bowing of the ulna with overlap of the fragments. The local disturbance may be small and confined to local tenderness and restriction of movement at the elbow In treatment the essential feature is to reduce and make rigid the ulna so that the dislocated radial head will drop back into place and stay reduced. This result is best achieved by using an intra-medullary nail down the olecranon and ulnar shaft (a Steinmann pin is a convenient instrument).

After pressing home the radial head the arm is immobilized in plaster from the axilla to the knuckles for 3 months. The correct diagnosis and then the stabilization of the ulna are the only means of eliminating a potential residual disability which can result from mal union or non-union of the ulna, unreduced dislocation of the radial head, cross union of radius and ulna at the level of the fracture, heterotopic calcification at the elbow or neural and vascular complications. In a small proportion of patients the Monteggia fracture-dislocation is backwards. The ulna fractures at the usual level but angulates backwards and the radial head accordingly follows suit (Fig. 46) Reduction by manipulation and traction is much easier to obtain than in the common forward

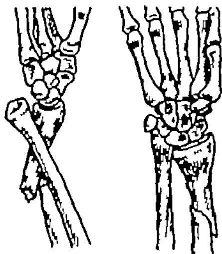


FIG. 47 Galeazzi fracture-dislocation.

dislocation and it may be stable. If there be any doubt about the stability then it must be solved by rendering the ulna rigid with an intramedullary pin.

In the Galeazzi fracture-dislocation the fracture occurs at the lower third of the radius and the lower fragment is angulated medially The inferior radio-ulnar joint is dislocated so that the lower end of the ulna moves backwards away from the carpus (Fig. 47) In children the fracture of the radius is often incomplete and the whole lesion is easily corrected by manipulation but care must be exercised to see that the lower end of the ulna really is back in position. In adults, sometimes the skin over the radius on the front of the forearm is punctured. The principle of treatment is that used for the Monteggia fracture namely that the fractured bone must be made rigid in order to avoid redisplacement of the dislocation. It is wise to proceed to open operation straight away and to fix the radial fragments with a four holed plate and screws and to immobilize the wrist in plaster after the dislocation has been corrected, for at least 8 weeks.

(18) Wrist

(*a*) COLLES'S FRACTURE. This is a very common fracture in people past middle age and it is caused by a fall on to the outstretched hand. The fracture is transverse 1 in above the lower end of the radius and the lower fragment is displaced backwards and radially and the fracture is impacted. The lower radial fragment is also tilted backwards

and rotated, and there is an associated fracture of the ulnar styloid process and forward dislocation of the lower end of the ulna because of separation of the inferior radio-ulnar joint (Fig. 48). Clinically the patient presents a swollen wrist with a "dinner fork" deformity restriction of finger movements and inability to rotate the wrist. It is essential that all the displacements of the lower radial fragment be corrected after disimpaction by traction on the hand. Failure to correct the backward tilt will cause limitation of palmar flexion. After reduction the wrist is best fixed without any dorsiflexion at the

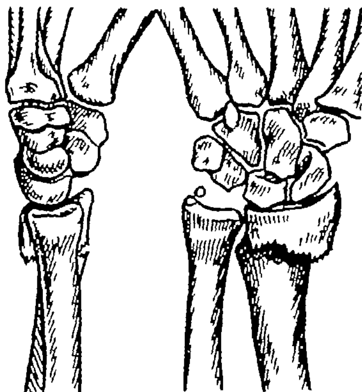


FIG. 48. Colles's fracture

wrist and preferably with some palmar flexion and in full ulnar deviation so that the radial fragment can be pulled over towards the ulna. Traction on the hand is continued whilst a posterior plaster strip is moulded to the forearm and wrist from just below the elbow to the heads of the metacarpals, and held in position with a cotton bandage. After the swelling has subsided and finger movements have been restored a check radiograph is taken on the fifth day and if satisfactory the plaster may be completed. The tendency to redisplacement of the fragments must constantly be remembered and the position of the fragments be repeatedly checked by radiography during the first fortnight after manipulation if any uncertainty should arise.

Immobilization of the fracture is required for 5 weeks. The greatest danger is stiffness of the fingers because of oedema which quickly fills up the hand after the accident and must be dispersed as soon as possible after the manipulation. Elevation of the hand and active finger movements must be practised until the swelling has subsided. The fingers

must be capable of reaching full extension with abduction and full flexion down to the palm and towards the wrist. Active exercises of the shoulder must be performed to prevent the otherwise common complication of stiff shoulder

(*b*) FRACTURE OF THE RADIAL STYLOID PROCESS. This fracture is usually caused by backfire whilst cranking an engine. The force drives the carpus outwards and backwards and the scaphoid impinges on the outer half of the articular surface of the lower end of the radius. Consequently the line of fracture runs from between the scaphoid and lunate upwards and outwards to about an inch up the radial shaft. Usually there is no displacement but sometimes the carpus travels with the radial fragment upwards and outwards reduction is effected by exerting traction on the hand in an ulnar direction If there has been no displacement then protection of the wrist by plaster cast for 4 weeks is sufficient. If there has been displacement, plaster immobilization as for a Colles's fracture is required for 6 weeks and no heavy work is permissible for 3 months.

(*c*) FRACTURE-SEPARATION OF LOWER RADIAL EPIPHYSIS. This lesion is really a greenstick Colles's fracture produced when a youth falls on to his outstretched hand. The lower epiphysis of the radius is displaced backwards and outwards and rips off the outer portion of the metaphysis as a triangular fragment. The shaft of the ulna usually accompanies the upper radial fragment and strains the lower ulnar metaphysis The treatment is similar to that for Colles's fracture but there is much less tendency to redisplacement of the fragments and growth does adjust minor inaccuracies of reposition. Crush injuries of the lower radial epiphysis usually cause no displacement of the epiphysis but predispose to premature fusion and consequent relative overgrowth of the lower end of the ulna.

(*d*) SMITH'S FRACTURE. This is a rare fracture of the lower end of the radius caused by falling on to the back of the hand. The line of fracture runs obliquely upwards and forwards in a coronal plane from the posterior border of the lower articular surface to the anterior surface of the bone about an inch above its lower margin. Consequently the lower radial fragment and the carpus slide upwards and the injury is clinically recognizable by the palpable prominence of the lower ends of the radius and ulna on the back of the wrist. Traction applied to the hand reduces the upward displacement and then the lower fragment of the radius can then be pressed home and maintained in position by immobilizing the wrist in moderate dorsiflexion in plaster for 5 weeks. Failure to achieve accurate reduction will impair dorsiflexion at the wrist and rotation of the forearm. Secondary displacement of the fragments is common.

(*e*) FRACTURE OF THE SCAPHOID This is a very common injury and is very frequently overlooked. The diagnosis of sprained wrist in a young person must never be made without initial radiography of the wrist taken in three planes and the examination must be repeated and only regarded finally as negative if no evidence of fracture can be determined several weeks after the injury The scaphoid is very susceptible to fracture because it forms part of both rows of carpal bones and because its waist lies between the styloid process of the radius and the mid-carpal joint. A fall on to the outstretched hand which produces forced dorsiflexion at the mid-carpal joint is prone to fracture the waist of the scaphoid in a line continuous with that of the mid-carpal joint (Fig. 49) The varying degree of radial deviation of the wrist at the moment of impact and the impingement of the radial styloid will determine the level of the more unusual scaphoid fractures at the tubercle or proximal pole of the bone. Clinically the local disturbance

is often slight and will encourage the unwary to dismiss the injury to the wrist casually as a sprain. Often there is pain and tenderness localized to the anatomical "snuff box" but there is rarely any easily demonstrable swelling.

Fractures of the scaphoid tubercle are extra-articular easily unite and do not constitute any problem. Fractures of the waist of the scaphoid have equal fragments which reduce spontaneously and are equally supplied with blood and will unite provided they are afforded complete immobilization for a sufficient length of time. In fractures of the proximal pole the small proximal fragment is very likely to die because it is cut off from

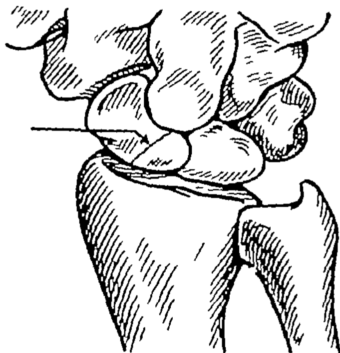


FIG. 49 Fracture of the carpal scaphoid.

its blood supply On the initial radiograph taken soon after the injury the fracture line may be well-nigh invisible but if the bone be left unsupported atrophy of the bone ends will ensue and a gaping fracture with separation of the fragments or even vacuolation will become visible (Fig. 22) Since there are no muscles attached to the bone, fixation of the fragments is entirely dependent on external immobilization by a plaster cast extending from just below the elbow down to the heads of the metacarpals. The cast must include the thumb down to the interphalangeal joint with the digit held in the optimum position for function so that the pads of the thumb and index finger can be approximated (Fig. 50). For a recent fracture the time of immobilization required is at least 8 weeks but it must be continuous until there is radiographic evidence of bony union.

Fractures of the proximal pole are likely to take longer to unite than fractures of the waist but if immobilization has been started late for either type of fracture union will be delayed for many months. If eventually non-union becomes established then the best

course for waist fractures is to curette out all the contents of the two fragments and to pack the shells with cancellous bone chips. Non union of the proximal pole fractures will react best to excision of the small proximal fragment. If however non-union has been discovered so late that secondary *carpal osteoarthritis* has supervened, then the problem is that of osteoarthritis of the wrist. Such painful wrists can be cured by

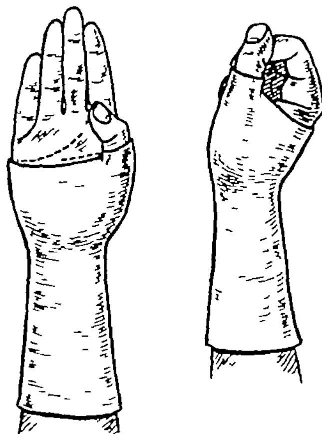


FIG. 50. Plaster for fracture of the carpal scaphoid.

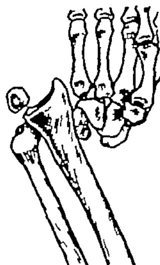


FIG. 51 Perilunar dislocation of the wrist.

arthrodesis but a stiff wrist is in itself a handicap and often it is best to use the wrist and accept the pain.

(*f*) CARPAL DISLOCATIONS. These lesions are caused by falls on to the outstretched hand and offer a large variety of dislocations and fracture-dislocations of the constituent bones of the wrist either individually or in combination. The two commonest injuries are dislocation of the lunate and peri-lunar dislocation of the carpus (Fig. 51) and the second is quite frequently modified to a trans-scapho-perilunar dislocation. Clinically there is evidence of a gross injury to the wrist but the œdema will tend to obscure the anatomy of the area except that the normal relationship of the styloid processes of the ulna and radius to one another will probably remain palpable. All the wrist and finger movements are restricted and painful. Radiographically the lesion is recognized by noting that the hand and carpus are in a plane posterior to that of the radius and the ball

of the capitate no longer articulates with the socket of the lunate any accompanying fracture of the scaphoid will be readily visible because of the displacement of the fragments Manipulation by traction on the hand with the wrist flexed and at the same time backward pressure applied to the lunate usually reduces the displacement fairly easily Immobilization in plaster with the wrist flexed for a week enables the œdema to subside, active movements of the fingers to be regained and to some degree heals the torn capsule. A second plaster with the wrist in the neutral position is required for a further 2 weeks. If there be an associated fracture of the scaphoid then plaster immobilization must be continued until the fracture has united.

(*g*) Dislocation of the Lunate. *It is possible that the plain dislocation of the lunate is the aftermath of a perilunar dislocation which has spontaneously reduced and,*

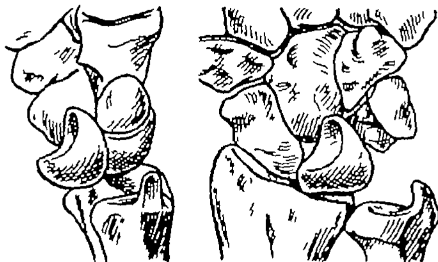


Fig. 52. Dislocated lunate.

during its return forwards, pushes the lunate before it, severing its posterior ligament The lunate, being still attached by its anterior ligament will rotate forwards and lie in front of the carpus (Fig. 52) Clinically although there is only a moderate swelling there is a tender fullness on the front of the wrist. The fingers are held flexed and cannot fully extend or be straightened. The patient may complain of numbness or paræsthesia in the index finger and there may be evidence of median nerve palsy The displacement of the lunate ought to be visible on the lateral radiograph Closed manipulation by traction on the hand and simultaneous pressure on the front of the wrist in flexion may be sufficient to reduce the displaced bone Repeated or prolonged manipulation is to be avoided and clear evidence of median palsy or failure of closed manipulation will call for open reduction. Accurate replacement of the lunate at operation is relatively simple but it must be achieved without injury to the intact anterior ligament otherwise there will be a decided risk that aseptic necrosis of the lunate will ensue. When dislocation of the lunate has been overlooked, especially in the presence of multiple injuries, it is better to excise the displaced bone rather than attempt to replace it.

(19) Hand

(*a*) FRACTURES OF THE METACARPALS. The majority of these injuries occur in men The first metacarpal is often fractured transversely about ½ in distal to the carpo-metacarpal joint but it is an impacted fracture and only gives outward bowing of the bone The symptoms and signs are minimal and the deformity is readily corrected by pressing over the fracture site whilst the head of the bone is abducted Immobilization in a plaster cast as used for fracture of the scaphoid is required for 3 weeks

Bennett's fracture is a fracture-dislocation of the base of the first metacarpal sustained during boxing or a fall. The fracture line runs obliquely from the mid point of the

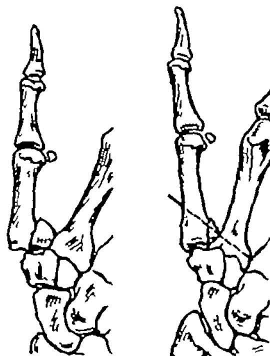


FIG. 53 Bennett's fracture.

articular surface of the base of the bone to the ulnar border of the shaft. The large distal fragment consisting of almost the whole of the thumb slides proximally leaving small triangular fragment of the metacarpal base articulating with the trapezium (Fig. 53) Pain and tenderness at the base of the thumb are accompanied by crepitus during movement thus distinguishing the lesion from the impacted transverse fracture or from a dislocation. Reduction by pressing over the base of the thumb during traction in its long axis is easily attained but it is unstable and even when traction is continued after a moulded plaster has been applied there is still a risk of redisplacement. Reduction is best maintained by thrusting a Kirschner wire through the reduced fracture into the base of the second metacarpal and cutting off the wire so that it is just buried under the skin (Fig. 53) A moulded plaster as for fractured scaphoid is applied and retained for 4 weeks after which the wire can be easily removed and union of the fracture will be sufficient to

of the capitate no longer articulates with the socket of the lunate any accompanying fracture of the scaphoid will be readily visible because of the displacement of the fragments. Manipulation by traction on the hand with the wrist flexed and at the same time backward pressure applied to the lunate usually reduces the displacement fairly easily Immobilization in plaster with the wrist flexed for a week enables the œdema to subside active movements of the fingers to be regained and to some degree heals the torn capsule. A second plaster with the wrist in the neutral position is required for a further 2 weeks. If there be an associated fracture of the scaphoid then plaster immobilization must be continued until the fracture has united.

(*g*) DISLOCATION OF THE LUNATE. It is possible that the plain dislocation of the lunate is the aftermath of a perilunar dislocation which has spontaneously reduced and,



FIG 52. Dislocated lunate.

during its return forwards pushes the lunate before it, severing its posterior ligament. The lunate being still attached by its anterior ligament will rotate forwards and lie in front of the carpus (Fig. 52). Clinically although there is only a moderate swelling there is a tender fullness on the front of the wrist. The fingers are held flexed and cannot fully extend or be straightened The patient may complain of numbness or paræsthesia in the index finger and there may be evidence of median nerve palsy The displacement of the lunate ought to be visible on the lateral radiograph. Closed manipulation by traction on the hand and simultaneous pressure on the front of the wrist in flexion may be sufficient to reduce the displaced bone. Repeated or prolonged manipulation is to be avoided and clear evidence of median palsy or failure of closed manipulation will call for open reduction. Accurate replacement of the lunate at operation is relatively simple but it must be achieved without injury to the intact anterior ligament otherwise there will be a decided risk that aseptic necrosis of the lunate will ensue. When dislocation of the lunate has been overlooked, especially in the presence of multiple injuries, it is better to excise the displaced bone rather than attempt to replace it.

(19) Hand

(*a*) FRACTURES OF THE METACARPALS The majority of these injuries occur in men The first metacarpal is often fractured transversely about ¼ in. distal to the carpo-metacarpal joint but it is an impacted fracture and only gives outward bowing of the bone. The symptoms and signs are minimal and the deformity is readily corrected by pressing over the fracture site whilst the head of the bone is abducted Immobilization in a plaster cast as used for fracture of the scaphoid is required for 3 weeks.

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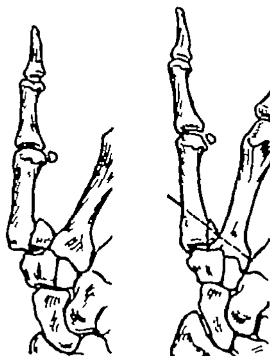


FIG. 53. Bennett's fracture.

articular surface of the base of the bone to the ulnar border of the shaft. The large distal fragment consisting of almost the whole of the thumb slides proximally leaving small triangular fragment of the metacarpal base articulating with the trapezium (Fig. 53). Pain and tenderness at the base of the thumb are accompanied by crepitus during movement thus distinguishing the lesion from the impacted transverse fracture or from a dislocation. Reduction by pressing over the base of the thumb during traction in its long axis is easily attained but it is unstable and even when traction is continued after a moulded plaster has been applied there is still a risk of redisplacement Reduction is best maintained by thrusting a *Kirschner wire through the reduced fracture* into the base of the second metacarpal and cutting off the wire so that it is just buried under the skin (Fig 53) A moulded plaster as for fractured scaphoid is applied and retained for 4 weeks after which the wire can be easily removed and union of the fracture will be sufficient to

give stability If untreated the fracture-dislocation gives a deformity with surprisingly little restriction of movement but osteoarthritis of the carpo-metacarpal joint will arise later and be the cause of pain and disability

Fracture of the shaft of any of the other metacarpal bones is a source of disability if malunion should occur If the fractures are transverse there is no overlap but the bones tend to buckle backwards because the carpal extensors dorsiflex the proximal fragment and the intrinsic muscles and long flexors tend to flex the distal fragment (Fig. 54) The consequent muscle imbalance gives a claw finger and the projection of the metacarpal head into the palm may press on a digital nerve and so limit the power of grasp The spiral fractures overlap and cause recession of the metacarpal head and malunion in rotation will cause deviation of the fingers and a tendency for them to cross over one another during flexion. The clinical signs are clear the lump on the back of the hand caused by the transverse fracture is easily palpable and the recession of the metacarpal



Fig. 54 Displacement in the metacarpal fractures.

head during flexion from the oblique fracture is easily visible. If there be no displacement of the fragments there will be only local tenderness. Reduction of the transverse fracture is effected by dorsi-flexing the wrist to relax the carpal extensors and by flexing the fingers to relax the long flexors and then pressure is applied over the swelling on the dorsum of the hand. The fragments are fixed by applying a moulded plaster cast from just below the elbow to the knuckles for 6 weeks but it is essential in all metacarpal fractures to leave the fingers free to carry out full active movements Failure to reduce the fracture accurately by manipulation calls for open reduction and impaction of the fragments into one another or if necessary intramedullary fixation with Kirschner wire must be used. For the spiral fractures manual traction will probably pull out the overlap but they are best fixed at open operation by binding the reduced fragments with catgut. External immobilization with plaster as for transverse fractures is required for 3 weeks.

Fracture of the neck of the metacarpal is transverse and angulated into the palm to produce local tenderness (Fig. 55) Reduction of the backward bow is achieved by pressing back the proximal phalanx, whilst the metacarpo-phalangeal joint is flexed to a right angle, against counter pressure over the proximal fragment of the metacarpal. The reduced fracture is fixed by moulding a dorsal strip of plaster from the finger tip to the wrist, keeping the metacarpo-phalangeal and proximal interphalangeal joints flexed at 90 degrees for 3 weeks. Failure to reduce the fragments by manipulation requires open operation and, if necessary fixation with Kirschner wire.

(*b*) *Carpo-metacarpal Dislocations.* The carpo-metacarpal joint of the thumb is frequently dislocated in boxers. The outward and backward displacement is similar to that of Bennett s fracture but there is no crepitus. The dislocation is readily reduced by exerting traction on the thumb and it is fixed in a moulded plaster as for fracture of the scaphoid for 3 weeks. The whole row of carpo-metacarpal joints may be

dislocated, usually backwards, but occasionally the metacarpal bases travel forwards. Reduction is achieved by pulling in the long axis of the extended fingers and pressing on the displaced metacarpal bases. Fixation in a moulded plaster for 3 weeks is required but active finger movements must start straight away Undiagnosed dislocations of the carpo-metacarpal joints show deformity but do not as a rule much hamper function.

(c) INJURIES TO THE FINGERS. Sprains, subluxations, and dislocations are all common injuries of the metacarpo-phalangeal joints and interphalangeal joints. These joints have radial ligaments so lateral angulation or hyperextension will rupture them or avulse a fragment of the bone Painful swelling results and perhaps preternatural mobility therefore splintage with the joints of the finger flexed to 60 degrees is required for 3 weeks. Failure to splint will cause permanent swelling, chronic pain, and some

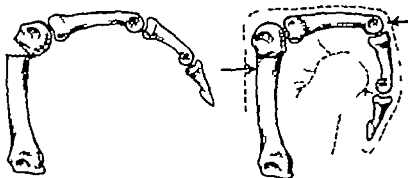


FIG. 55 Fracture of the neck of a metacarpal.

permanent disability Dislocations of interphalangeal joints are common and usually are easily reduced by traction. When closed reduction fails it is because the head of the proximal bone has pierced the anterior capsule and needs open reduction. Almost all chronic finger dislocations require open reduction and permanent restriction of movement is to be expected. If the chips off the base of the phalanx are tilted or included in the joint open reduction is essential. Some finger dislocations reduce spontaneously although often incompletely Restricted range of movement may be unaccounted for until residual subluxation has been noted on the radiograph (Fig. 25).

Fractures of the phalanges occur most frequently in the proximal bones at the base shaft or condyle and they are often comminuted. The fractures of the shaft angulate forwards because of the pull by the interossei and lumbricals on the proximal fragment. Reduction is usually possible by traction and then the finger must be immobilized in flexion for 3 weeks by a dorsal plaster strip. If the fracture be unstable then traction through the distal phalanx by pin (and not through the pulp of the finger) is required in addition to the plaster Condylar fractures have a very serious prognosis for function because a *stiff* proximal interphalangeal joint is almost inevitable. Immobilization with plaster *strip until* the pain and swelling subside is advisable but free active movement must be started as soon as possible and the position of the *fragments* disregarded. Fractures of the middle phalanx also angulate forwards because of the *pull of the* flexor digitorum sublimis on the proximal fragment and after reduction *they need* anterior splintage with the joints flexed for 3 weeks. Fractures of the distal phalanx are usually

crush fractures except for the avulsion fractures of the long extensor tendon causing a mallet deformity Pain and tension of the hæmatoma under the nail is the main trouble and this is relieved by puncturing the nail with a red hot needle or a dental drill The *avulsion fracture of the base of the distal phalanx* is treated by fixing the finger in plaster with the proximal interphalangeal joint flexed and the distal interphalangeal joint hyper extended for a month. The worst effect of an untreated mallet finger is to produce a hyperextension deformity at the proximal interphalangeal joint which is more difficult to treat than the original mallet deformity it requires flexion and then restriction of extension by using a glove splint (Fig. 56)

(20) Cervical Spine

(*a*) Injury to Atlas and Axis. Fracture of the atlas is caused by a blow on the top of the head. There is usually pain radiating to the occipital region of the scalp

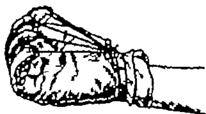


Fig. 56. Glove splint.



Fig. 57 Caliper traction of the skull.

from irritation of the variable cutaneous supply of the posterior primary ramus of the first cervical nerve. The lateral masses are forced apart and the posterior arch fractures on each side. The fragments are held in position by the transverse ligament unless the anterior arch is also fractured. Injury to the spinal cord is either severe and fatal or more often, it is absent. The patient balances his head by muscle spasm and when he changes position supports his head in his hands. Reduction of the fracture is not required but support for the head with a polythene collar enables the muscles to relax and protects the neck against sudden movements of the head. If there be any cord injury skull traction with calipers for 8 weeks (Fig. 57) is required and then the neck will be stable enough to rely on the protection of a polythene collar

Forcible flexion of the head will cause forward dislocation of the atlas if the transverse ligament rupture or the odontoid process fracture. The danger to the spinal cord is greater when the odontoid process remains intact to impinge upon it, than if the odontoid be fractured. Reduction is effected by skull traction and then the neck is immobilized in plaster in full extension for 3 months. Unreduced dislocations not infrequently occur and present as progressive cord compression syndromes correction by skull traction and fixation with bone graft will be required. In old people hyper extension injuries of the atlas, odontoid, or axis, occur from falls on to the face If there be no displacement of the vertebræ which would be likely to prove fatal, the injury is treated by flexing the head. Immobilization of the neck in a polythene collar is required for 3 months.

(*b*) Hyperflexion Injuries to the Lower Cervical Spine. Hyperflexion of the neck most commonly causes dislocation of the lower cervical spine but sometimes it

produces compression of the body of a vertebra without any dislocation The fracture in itself may be of little importance since the articular processes are not displaced but the association of acute disc prolapse and cord compression may be as serious as a dislocated neck The compression fracture of the vertebral body will produce abnormal neurological signs when it is crushed by the body above, so that the anterior portion is broken away (the so called tear-drop fracture), thus allowing the inferior margin of the posterior fragment to slip backwards into the spinal canal (Fig. 58) Acute prolapse of a cervical disc and the tear-drop fracture usually react favourably to skull traction but if the cord compression be unrelieved then laminectomy will be required. The ordinary compression fracture only needs immobilization of the neck in plaster in full extension. Momentary dislocation of the lower cervical spine tends to leave a subluxation not infrequently associated with serious cord damage. Apart from gross injury the sudden jerk of the head forwards from rapid deceleration of a car is sufficient to cause momentary dislocation. Lateral radiography of the cervical spine in the flexed position will reveal the subluxation and may show narrowing of the disc space. Immobilization of the neck in plaster is essential for at least 8 weeks. Failure to attain stability of the neck may lead to recurrent subluxation of the articular processes and so cause root pain and paræsthesia It will call for spinal fusion. Dislocation of the cervical spine tends to occur between the fifth and sixth vertebræ and the upper segment of the spine slips forward. Very often there is complete tetraplegia but the phrenic nerve escapes and life is preserved The paralysis may be complete and permanent from transection of the cord at the time of the accident and when spontaneous reduction has occurred the radiographs may show no abnormality


FIG. 58. Tear drop fracture of the cervical spine.

If the dislocation be still present reduction will relieve cord compression and recovery of paralysis may still be possible. Reduction requires powerful traction by means of skull calipers and countertraction by body weight on an inclined plane until the articular processes are disengaged If traction should fail the facets can usually be unlocked at open operation. When the articular processes remain obstinately locked then the superior articular facets of the lower vertebra may be excised to facilitate reduction above the seventh cervical vertebra this operation is in danger of wounding the vertebral artery If it has been necessary to render the cervical spine unstable by excision of a facet then immediate local bone graft or wiring is advisable. After skull traction for 6 weeks protection of the neck with a polythene collar will be required. Even so there may be a tendency for redislocation to occur in which event operative fixation will be necessary

(c) HYPEREXTENSION INJURIES OF THE LOWER CERVICAL SPINE. Sudden hyper extension of the neck in old people is particularly dangerous because the cervical column is already stiffened by degenerative changes in the discs, heterotopic calcification in the ligaments and is weakened by osteoporosis so that it becomes a brittle stalk. A fall on to the face is sufficient to rupture the anterior common ligament of the senile cervical spine and the consequent sudden angulation of the spine compresses the spinal cord between the vertebral body in front and the lamina behind. Lateral radiographs may show no evidence of displacement of the vertebræ but the history of the fall and abrasions

on the face and forehead are sufficient clues to the nature of the lesion and the cause of the tetraplegia. Traction is not required for hyperextension injuries because there is no displacement to reduce. In the presence of neural complications it is sufficient to treat the patient lying free in bed. For lesser degrees of injury only protection of the neck by means of a polythene collar during ambulation is required until a stable fibrous ankylosis has occurred.

(21) Dorsi-lumbar Spine

Almost all fractures and fracture-dislocations in this area are caused by forced hyperflexion usually from direct violence at a higher level where there is contusion and

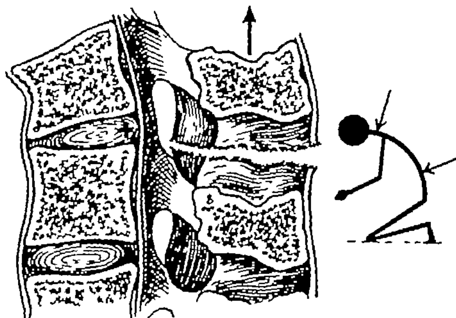


FIG. 59 Mechanism of the dorsi-lumbar fractures.

tenderness of the overlying soft parts Two thirds of the injuries involve the twelfth dorsal and first and second lumbar vertebræ (Fig 59)

(*a*) ANTERIOR WEDGE FRACTURES. Very often the degree of wedging of the vertebral body is slight. When there is severe crushing of a vertebral body the leverage about the posterior half of the subjacent intervertebral disc may cause rupture of the corresponding interspinous ligament and upward displacement of the inferior facets of the upper vertebra (Fig. 59). The separation of the spinous processes is clearly visible in the lateral radiograph. It is important to differentiate this *unstable* fracture-subluxation from the mild anterior wedge fracture which is *stable* In the absence of adequate immobilization the fracture-subluxation is a potential fracture-dislocation with all its attendant danger of spinal cord damage.

(*b*) LATERAL WEDGE FRACTURES. These are flexion rotation injuries which produce unilateral wedging of the body of the vertebra, fractures of the transverse processes on the convex side and damage to the intervertebral joint on the concave side (Fig. 60).

It is frequently associated with tearing of the psoas muscles and gross retroperitoneal hæmorrhage. The diagnosis is clear from the appearances on the antero-posterior radiograph but clinically the retroperitoneal hæmorrhage may cause paralytic ileus. The prognosis for return of full function is poor; associated disc damage may cause much root pain and the soft tissue injuries are severe enough to be responsible for residual pain. Reduction of the fracture is difficult and it is subject to redisplacement and spinal bone grafting may be required. Sometimes it is associated with paraplegia from traction on nerve roots and the dentate ligament on the convex side.

(c) Fracture-dislocations. These injuries are almost always associated with paraplegia. They are the next stage after the anterior wedge fracture-subluxation injuries



Fig. 60. Lateral wedge fracture.



Fig. 61. Fracture dislocation of spine.

when the external force is *still* unspent (Fig. 61). Once the posterior interspinous ligament has ruptured then any continuing force will carry the upper vertebra forwards. The inferior facets of the upper vertebra will ride over the superior facets of the lower vertebra and become locked or, more commonly, the superior facets of the inferior vertebra will fracture and the unimpeded forward displacement of the upper vertebra will transect the spinal cord. Reduction by turning the patient into the prone position is usually sufficient to show whether the facets are locked. Any attempt to hyperextend the spine in the presence of locked facets will increase the damage to the spinal cord or cauda equina.

(*d*) Neural Arch Fractures. These are rotation injuries and are often associated with fractures of the transverse processes. The neural arch fracture is through the lamina and, if bilateral, will allow the inferior facets of the upper vertebra to slide forward, leaving the superior facets of the lower vertebra in position. In the upper lumbar vertebræ the shift forwards is very little and union will occur without further displacement. At the fourth and fifth lumbar vertebræ a bilateral laminar fracture is subjected to forward shearing stress by the body weight and spondylolisthesis will occur.

In the treatment of hyperflexion injuries of the spine it is of first importance to differentiate the *unstable lesions from the stable*. Redisplacement after adequate reduction

is caused by comminution of the vertebral body crushing of an intervertebral disc or rupture of the interspinous ligament. The correction of the primary deformity of the compressed vertebral body by hyperextension is temporary because a secondary deformity equal to the first often occurs during the first year after the plaster jacket, used at first to maintain reduction, has been discarded. The presence of a compressed vertebral body of a degree which is unaccompanied by rupture of the interspinous ligament and subluxation is compatible with full painless function and consolidation is rapid in the primary compressed position.

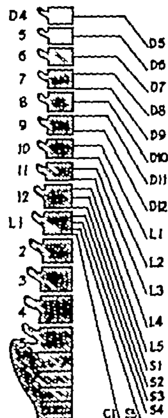


FIG. 62. Cord and root lesions at the level of the dorsi-lumbar junction.

(c) TREATMENT In the absence of any neural complications stable fractures, which include anterior and lateral wedge fractures and all laminar fractures above the fourth lumbar level, are treated functionally The patient is kept in bed for 4 weeks to relieve pain and to heal the soft tissue damage and during this time he carries out active hyper-extension exercises. After getting up, a full rehabilitation scheme in the gymnasium is followed until the patient is fit for heavy labour Unstable fractures without neural complications include all fractures or subluxations with rupture of the interspinous ligament, all fracture-dislocations and all laminar fractures at the level of the fourth and fifth lumbar vertebræ These patients require a plaster jacket applied in the neutral position so that rapid anterior fusion of the vertebral bodies can occur

(22) Traumatic Paraplegia

This is a complication of fracture-dislocation of the lumbar spine caused by damage to the spinal cord or nerve roots. No recovery of function is possible after division of the axons in the spinal cord but the nerve roots may have power of regeneration. The spinal cord ends at the lower border of the body of the first lumbar vertebra and the vertebræ below shelter the cauda equina. All the lumbar and sacral segments of the cord lie between the ninth dorsal and the first lumbar vertebral bodies. Injuries above the eleventh dorsal vertebra cause cord lesions, those below the first lumbar vertebra cause root lesions but at the dorsi-lumbar junction the neural lesions are mixed cord and root.

The level of the cord lesion can be accurately determined by radiography because it is at the level of the fracture-separation of the vertebræ If the nerve roots at the same level are also severed, clinical evidence of paralysis will relate to their cord segment at a higher level. The disparity between the clinical and radiographic findings only occurs in the area of mixed cord and root lesions Thus a fracture-dislocation at the dorsi-lumbar junction will sever the cord at the first sacral segment and the nerve roots of all the lumbar segments (Fig. 62). The clinical level of paralysis and anæsthesia will, therefore, be at the first lumbar segment of the cord.

Immediately after the injury there is a complete flaccid paraplegia below the level of the lesion as a result of spinal shock This shock may last for weeks and as it recovers, the flaccid paralysis changes to one which is spastic. Reflexes become exaggerated but if anæsthesia remains complete then these are the signs of cord transection and no recovery will occur The anal and bulbo-cavernosus reflexes usually remain intact or return very early and point to a bad prognosis.

The early flaccid paralysis may however be caused by spinal concussion from which a complete motor and sensory recovery will occur within 3 days. Spinal concussion is a temporary neurapraxia and has no relation to spinal shock which is always associated with an irrecoverable cord lesion. The recovery from spinal concussion may be rapid within the first 12 hours and it is characterized by return of sensation and motor power and not by individual reflex activity

If the vertebral fracture be stable, no treatment of the bone lesion is required If the spinal lesion be unstable then it is best made stable by bolting together the two spinal fragments with a plate on each side of the spinous processes fixed with four bolts (Fig. 63) This procedure avoids the use of any external immobilization and the patient can be treated free in bed for his paraplegia Care must be exercised to minimize torsional stresses during the 2 hourly turnings of the patient required for the prevention of bed sores.

The prime causes of discomfort and death in the paraplegic arise out of complications which are mainly preventable therefore, proper treatment must be instituted from the onset of the paralysis The patient ought to be sent to a special paraplegia centre, even though a long distance away because wrong or inadequate early care may mean a subsequent delay of months in hospital. The special defects of the paraplegic are lowering of the viability of the skin and the paralysis of the bladder and bowel Anæsthesia and immobility disturbs the vaso-motor control and makes the skin more vulnerable to minor trauma than in the normal patient and this is particularly so during the period of spinal shock. Irrecoverable damage occurs in the deep vessels before any skin changes appear By the time it has become clear that the skin is dying, there is often a plug of necrotic tissue beneath it down to the bone The damage required to produce a deep pressure sore may easily be done in the first 4 hours. Such sores are not confined to the usual pressure points. Ulcers progressing to fistulæ may occur on the under surface of the penis where it rests on the edge of a urinal or is traumatized by strapping for a catheter Ordinary routine care for the skin is not sufficient but 2-hourly turning of the patient, whether the spine be stable or unstable, is essential. No plaster or other splintage is to be permitted. When the spine becomes stable the patient must be taught to turn himself and to take a daily bath. Established bed sores require an improvement in the patient's general condition by the use of high protein diet and blood transfusions even in the absence of anæmia. Locally hypertonic saline baths are supplemented by the systemic administration of antibiotics, and finally plastic surgery may be needed.

Paralysis of the detrusor muscle of the bladder allows it to fill and no urine can be passed until there is retention with overflow In cauda equina lesions, eventually the detrusor acquires some tone and an *autonomous* bladder will develop. In higher cord lesions, after spinal shock has passed, reflex action in the bladder reappears and an *automatic* bladder may be established in which distension stimulates the detrusor and relaxes the sphincter Bladder drainage ought to be made efficient within 24 hours of the

onset of injury but it is better to delay for 48 hours for the benefit of treatment in a paraplegia unit rather than permit indiscriminate catheterization An indwelling Foley catheter is best because it is self retaining and the least irritant. The danger of an in dwelling catheter is the establishment of urethritis therefore it ought to be changed on alternate days (with full aseptic precautions) for the first 3 weeks and thereafter twice weekly A Foley catheter of size 18 French or smaller is used to avoid pressure sores in the urethra and allow urine to trickle alongside the catheter as well as through it. The bladder must be washed out and care taken to evacuate all residual urine, which pools at the bottom of the bladder and is inevitably purulent. The patient must have a large fluid intake and this is a duty which he must perform himself in order to avoid urinary infection and calculus formation. The urine must be kept slightly acid by the administration of daily doses of ammonium chloride. The control of the paralysed bowel is not so great a problem as the care of the paralysed bladder Enemata twice weekly prevent any accumulation of fæces in the constipated gut. Collections of hard fæces give a spurious diarrhœa and manual removal of the scybala is required.

Rehabilitation consists of strengthening the arm and shoulder girdle muscles for the use of crutches, training in the use of a wheel chair the provision of knee hinged callipers with easily accessible locks and instruction in three point walking. The main late complications are muscle spasms and pain in the legs. The spasms may be very troublesome and, for a patient whose spinal cord has been completely transected, it is best to convert the spastic into a flaccid paraplegia by intrathecal injections of alcohol which will destroy the lower fragment of the cord and its roots. If the spasms be localized because the cord lesion is incomplete then they may be quelled by peripheral neurectomy division of spastic muscles or falling all else, by excision of the lower fragment of the spinal cord.

(23) Chest

(a) Fractures of the Ribs. Direct blows to the ribs may produce a local crack fracture. Crush injuries cause the ribs from the third to the tenth inclusive to snap in the region of their costal angles. The first and second ribs usually escape since they are protected by the clavicle Pain and shallow respirations make it more comfortable to sit than to lie down. Union usually occurs within 12 days and although consolidation may be delayed for months, recovery of function is satisfactory in about a month. Injection of local anæsthetic into the fractures gives the best and quickest relief of pain and no form of immobilization is necessary A severe crush injury may cause a portion of the chest wall to be staved in and so seriously embarrass respiration as to require an artificial respirator The respiratory embarrassment in chest wall injuries may be caused by pneumothorax, hæmothorax, lacerated lung, but may also be due to the paradoxical movement of a floating piece of chest wall. The chest complications of severe chest wall injuries are preferably treated by a thoracic surgeon.

(b) Fractures of the Sternum Isolated fracture at the junction of the manubrium and body of the sternum occur in motor accidents from a blow on the chest by the steering wheel and the body of the sternum is displaced posteriorly Rapid union occurs Associated fracture of the bodies of the upper dorsal vertebræ is a common enough source of later backache to make it incumbent upon the surgeon to have radiographs of the dorsal spine taken at the time that the diagnosis of fracture of the sternum is made.

(24) Pelvis

(a) FRACTURES. Avulsion fractures occur in youths at the anterior superior and inferior iliac spines and at the ischium as a result of sudden muscle contraction. Union is rapid and complete and there is no residual disability. Separate fractures of the pelvic ring occur; they are single and so there is no disruption of the pelvic ring. The lesions heal without any external immobilization and rest in bed is required only until the pain and hæmatoma have subsided. The bones affected are the pubic rami (Fig. 64), the body of the ilium, the sacrum, and the coccyx. Union of coccygeal fractures is often delayed because of the muscle pull in almost all directions. Excision of the coccyx for persistent

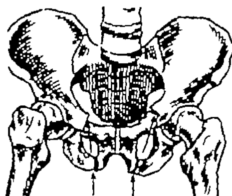


FIG. 64. Fracture of the pubic rami.

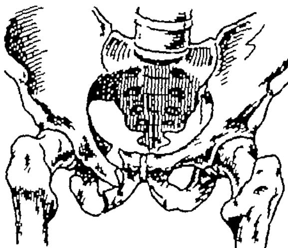


FIG. 65. Disruption of the pelvic ring.

pain and disability when sitting or defæcating is by no means certain of banishing all the symptoms and may lead to an awkward coccygeal fixation syndrome.

(b) DISRUPTION OF THE PELVIC RING. Disruption consists of a pubic injury associated with dislocation of the sacro-iliac joint (Fig. 65) or with an iliac fracture in the vicinity of the sacro-iliac joint. The dislocated sacro-iliac joint is about twice as common as the iliac fracture and carries a much worse prognosis for residual pain. Disruption of the pelvic ring occurs as a result of direct violence in which the pelvis is crushed. The pubic bones separate and the pelvis opens out hinging at the posterior break in the ring and not infrequently there is upward displacement of the injured side of the pelvis. Injury to the pelvic viscera and a large retroperitoneal hæmorrhage are much less frequent than might be expected, but they are very serious complications when they do occur. The visceral injuries are extraperitoneal tears of the bladder and rupture of the urethra. The surgical treatment of the visceral injuries takes precedence over all else but reduction of the pelvic displacement may be of material help in catheterization of the ruptured urethra. Large retroperitoneal hæmorrhages are caused by rupture of the iliolumbar artery and the bleeding is severe enough to produce an alarming fall in blood pressure. Local treatment of the bleeding point is out of the question but the blood pressure must be maintained by blood transfusion until the bleeding stops.

Reduction and fixation of the disrupted pelvis is achieved by placing the patient in a broad canvas sling kept extended from the level of the iliac crests to below the trochanters by being threaded on to wooden rollers. The sling is suspended from an over head frame with the cords from each roller crossed to the other side and weighted sufficiently to raise the pelvis from the bed. This form of lateral compression apposes the separated portions of the pelvic ring at the front and counteracts the outward rolling force of the extended lower limbs. The hips are flexed by cradling the lower limbs on Braun's splints and any upward displacement of the injured side is corrected by applying skeletal traction through the tibia at the level of its tubercle for 12 weeks and then weight bearing and activity may begin. After 6 weeks from the injury the traction weights on the leg are released for active leg exercises. Recovery from the fracture-separation disruptions ought to be sufficient to permit return to heavy labour but the sacro-iliac dislocations may cause enough residual pain to call for sacro-iliac arthrodesis.

(25) Hip

(a) DISLOCATION This injury is becoming increasingly common either as a posterior dislocation in motor transport collisions or as an anterior dislocation in mining. When the thigh is flexed and adducted the head of the femur rests on the posterior capsule of the hip joint and not in the acetabulum. A force applied to the flexed knee will readily rupture the capsule of the hip and allow the femoral head to travel backwards. If the hip be in the neutral position at the time of the accident then it is probable that the posterior rim of the acetabulum will be fractured. When the hip is flexed and abducted, which is the usual position for a coal getter in a low seam, a fall of roof on to the pelvis will displace the femoral head forwards. The characteristic flexion, adduction and medial rotation deformity of the posterior dislocation differentiates the injury from fracture of the neck of the femur which allows lateral rotation of the lower limb to occur by reason of its weight (Fig. 66) Radiographic confirmation of the nature and extent of the injury is required especially to note any accompanying fracture. Fracture of the posterior rim of the acetabulum may obstruct reduction or may render reduction unstable.

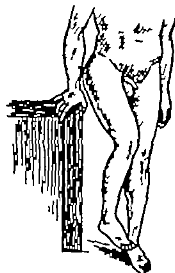


FIG. 66 Posterior dislocation of the hip.

Reduction is effected by placing the anæsthetized patient on the floor with the pelvis firmly fixed by an assistant. Rotation of the lower limb into the mid-position with the hip and knee flexed will enable the femoral head to be lifted into the acetabulum. After manipulation, anterior and lateral radiographs are required. Some dislocated hips are complicated by fracture of the acetabular rim but manipulation is usually capable of reducing the whole displacement. A few fractured portions of the acetabulum will require open reduction and screw fixation in order to ensure that re-dislocation will not take place. When reduction is complete the patient is allowed to lie free in bed until pain has gone and then active non-weight bearing movements may be started without further

demur After 3 weeks the patient may be allowed to start walking. Many surgeons immobilize the reduced dislocated hip in a plaster spica for 6 weeks with the aim of avoiding the complications of redislocation, avascular necrosis of the femoral head and subperiosteal ossification. Redislocation ought not to occur if stable reduction has indeed been achieved and the other two complications, as similarly in the presence of fracture of the femoral neck, are probably determined at the time of the injury and hence are unaffected by precautionary immobilization. Check radiographs at 3-monthly intervals are advisable in order to note the state of the bone architecture of the femoral head for at least 18 months after the accident.

Fracture-dislocation of the hip includes central dislocation of the hip associated with fracture of the head, neck, or shaft of the femur In central dislocation the floor of the

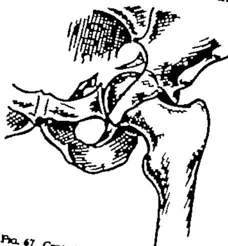


Fig. 67 Central dislocation of the hip

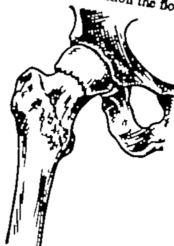


Fig. 68 Intracapsular of the femoral neck.

acetabulum is shattered when the force along the femoral neck drives the femoral head into the pelvis (Fig. 67). The displaced femoral head is best withdrawn by applying skeletal traction at the level of the tibial tubercle but the comminuted acetabular floor remains unreduced. Nevertheless a good functional result is to be expected but eventually osteoarthritis of the hip will obtain It is not unknown for the dislocation of the hip accompanying fracture of the femoral shaft to be overlooked in treating the more obvious injury The fracture of the femur must be rendered rigid by open reduction, preferably by an intramedullary nail, so that the dislocation may be managed in the ordinary way Fracture of the neck of the femur in association with a dislocated hip is best treated by replacing the femoral head by a metal prosthesis.

(b) Intracapsular Fractures of the Femoral Neck. Formerly these fractures have been classified into abduction or valgus fractures and adduction or varus fractures. These categories are merely stages in the separation of the fragments depending upon the degree of violence and the amount of skeletal resistance The peripheral fragment is rotated outwards on its long axis and the femoral head slips downwards behind the femoral neck which is pointing forwards In the abduction fracture, which is the early stage, there is very little displacement, it is relatively stable and it ought to unite easily if the fragments are firmly fixed (Fig. 68). The intermediate fracture shows greater

displacement of the fragments but there is still some contact. In the adduction fracture there is no contact between the fragments Failure to fix the fragments in the early abduction stage may permit further displacement and perhaps separation of the femoral head. Union depends on the shearing strain to which the reduced fracture will be subjected and this varies directly with Linton s angle of inclination A line drawn on the radiograph through the fractured surface of the inferior fragment after reduction of the displacement, to join a perpendicular to the long axis of the femoral shaft will give the angle of inclination (Fig. 69) When the angle is 35 degrees or less the shearing force will be minimal and the prognosis for union is good. When the angle is between 35 degrees and 55 degrees the shearing force will be great enough to make the prognosis more guarded even when the fragments have been satisfactorily fixed. When the angle

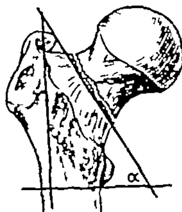


FIG. 69 Linton's line of inclination.



FIG. 70. Smith Petersen nail

is more than 55 degrees consideration must be given to reducing it by performing a subtrochanteric wedge osteotomy which is fixed with a plate attached to the trifin nail used for fixation of the fracture.

Most surgeons still use the Smith Petersen trifin nail for fixing intracapsular fractures of the femoral neck for all patients under 75 years of age (Fig. 70) Reduction of the fracture is obtained by internally rotating the limb There is, however a high incidence of avascular necrosis of the femoral head and it is claimed that the frequency of this complication can be reduced by using two Moore s pins because they disturb the vascularity of the femoral head less than the blunt nosed nail. The practice of combining a trifin nail with a bone graft is calculated to disturb the circulation to the injured femoral head even more than the nail alone More recent developments have concentrated on achieving impaction of the fragments by lag screws, stud bolts, or spring loaded screws. In very old people replacement of the femoral head by an acrylic or steel prosthesis is the method of choice because of the rapidity of convalescence and of the urgent need for such patients to become mobile as soon as possible.

Avascular necrosis of the femoral head occurs but slowly and it is not compatible with bony union. Monthly radiographs are required after internal fixation of intra capsular fractures to check the position of the nail and to assess the condition of the femoral head. Gradual slipping out of the nail is often an early sign of necrosis of the

demur After 3 weeks the patient may be allowed to start walking. Many surgeons immobilize the reduced dislocated hip in a plaster spica for 6 weeks with the aim of avoiding the complications of redislocation, avascular necrosis of the femoral head and subperiosteal ossification. Redislocation ought not to occur if stable reduction has indeed been achieved and the other two complications, as similarly in the presence of fracture of the femoral neck, are probably determined at the time of the injury and hence are unaffected by precautionary immobilization. Check radiographs at 3-monthly intervals are advisable in order to note the state of the bone architecture of the femoral head for at least 18 months after the accident.

Fracture-dislocation of the hip includes central dislocation of the hip associated with fracture of the head, neck, or shaft of the femur In central dislocation the floor of the

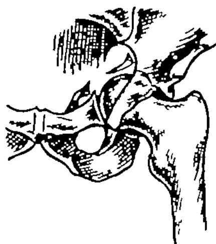


FIG. 67 Central dislocation of the hip.



FIG. 68. Intracapsular of the femoral neck.

acetabulum is shattered when the force along the femoral neck drives the femoral head into the pelvis (Fig. 67). The displaced femoral head is best withdrawn by applying skeletal traction at the level of the tibial tubercle but the comminuted acetabular floor remains unreduced. Nevertheless a good functional result is to be expected but eventually osteoarthritis of the hip will obtain. It is not unknown for the dislocation of the hip accompanying fracture of the femoral shaft to be overlooked in treating the more obvious injury The fracture of the femur must be rendered rigid by open reduction, preferably by an intramedullary nail, so that the dislocation may be managed in the ordinary way Fracture of the neck of the femur in association with a dislocated hip is best treated by replacing the femoral head by a metal prosthesis.

(*b*) INTRACAPSULAR FRACTURES OF THE FEMORAL NECK. Formerly these fractures have been classified into abduction or valgus fractures and adduction or varus fractures. These categories are merely stages in the separation of the fragments depending upon the degree of violence and the amount of skeletal resistance. The peripheral fragment is rotated outwards on its long axis and the femoral head slips downwards behind the femoral neck which is pointing forwards. In the abduction fracture, which is the early stage, there is very little displacement, it is relatively stable and it ought to unite easily if the fragments are firmly fixed (Fig. 68) The intermediate fracture shows greater

displacement of the fragments but there is still some contact In the adduction fracture there is no contact between the fragments. Failure to fix the fragments in the early abduction stage may permit further displacement and perhaps separation of the femoral head. Union depends on the shearing strain to which the reduced fracture will be subjected and this varies directly with Linton's angle of inclination A line drawn on the radiograph through the fractured surface of the inferior fragment after reduction of the displacement, to join a perpendicular to the long axis of the femoral shaft will give the angle of inclination (Fig. 69) When the angle is 35 degrees or less the shearing force will be minimal and the prognosis for union is good. When the angle is between 35 degrees and 55 degrees the shearing force will be great enough to make the prognosis more guarded even when the fragments have been satisfactorily fixed. When the angle

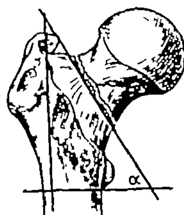


FIG. 69 Linton's line of inclination.



FIG. 70 Smith Petersen nail.

is more than 55 degrees consideration must be given to reducing it by performing a subtrochanteric wedge osteotomy which is fixed with a plate attached to the trifin nail used for fixation of the fracture.

Most surgeons still use the Smith Petersen trifin nail for fixing intracapsular fractures of the femoral neck for all patients under 75 years of age (Fig. 70) Reduction of the fracture is obtained by internally rotating the limb There is, however a high incidence of avascular necrosis of the femoral head and it is claimed that the frequency of this complication can be reduced by using two Moore's pins because they disturb the vascularity of the femoral head less than the blunt-nosed nail. The practice of combining a trifin nail with a bone graft is calculated to disturb the circulation to the injured femoral head even more than the nail alone. More recent developments have concentrated on achieving impaction of the fragments by lag screws, stud bolts, or spring loaded screws. In very old people replacement of the femoral head by an acrylic or steel prosthesis is the method of choice because of the rapidity of convalescence and of the urgent need for such patients to become mobile as soon as possible.

Avascular necrosis of the femoral head occurs but slowly and it is *not compatible* with bony union. Monthly radiographs are required after internal fixation of intracapsular fractures to check the position of the nail and to assess the condition of the femoral head. Gradual slipping out of the nail is often an early sign of necrosis of the

femoral head and replacement of the nail is unlikely to promote union. In the younger patient no further weight bearing is permitted for many months until some sign of union of the fracture is radiographically visible. In most patients it is better to accept the prognosis indicated by the slipping nail of inevitable necrosis of the femoral head and to remove the nail and excise the head and neck of the femur This operation enables early ambulation to take place with the aid of a ring-topped walking caliper and the hip is eventually much less unstable than might be expected

(c) Extracapsular Fractures of the Femoral Neck. All these fractures unite without difficulty but often not in a fully reduced position. Fortunately most degrees of residual deformity can be adequately compensated or be corrected later by *subtrochanteric osteotomy* *The fractures occur at the base of the femoral neck and pursue a*



Fig. 71 Nail plate.

line either upwards and outwards from the lesser trochanter or less commonly downwards, and outwards. In the first group the important point to decide is whether or not the *calcar femorale* is intact. When there is no disturbance of the calcar femorale there is no displacement of the fracture and union will be rapid. A small degree of over lap of the calcar femorale can be corrected by manipulation and stable reduction of the fracture be obtained but if the overlap be uncorrected then the fracture will heal in the position of coxa vara. In the second group cortical overlap or comminution is usual but firm union will take place in the varus position.

The treatment of choice whenever possible is internal fixation with trifin nail and attached plate screwed into the upper femoral shaft (Fig. 71) (alternatively with a combined nail plate in one piece) with the limb in a position of a few degrees of external rotation. Internal fixation is only suitable for fractures without cortical comminution otherwise it will not be stable. The advantage of internal fixation is the rapidity with which the patient can be mobilized and in old people this is a matter of importance. When conservative treatment has to be used then Russell traction applied through a pin at the tibial tubercle is the best method because no splint is required, the patient is easily moved about the bed and rotation of the limb can be fully controlled.

(d) Fractures of the Femoral Neck in Children These fractures are uncommon and usually incomplete. Reduction is difficult, union is certain but avascular necrosis

of the femoral head occurs in a high proportion The injury is to be differentiated from a slipped capital epiphysis of the femur which is a much more common lesion. Forcible manipulation materially increases the risk of avascular necrosis and it is best to accept the varus deformity and obtain union of the fracture by immobilizing the limb in plaster Later any coxa vara can be corrected by subtrochanteric osteotomy

(26) Thigh

(*a*) FRACTURE OF UPPER THIRD FEMUR. This is a transverse fracture and most commonly associated with Paget's disease. The upper fragment is abducted by the gluteal muscles and flexed by the ilio-psoas. The lower fragment is adducted by the powerful adductor muscles and pulled up so that the sharp upper end of the lower fragment may impinge upon the capsule of the hip or the ischial tuberosity Consequently there is wide separation of the fragments with overlap. The patient lies in pain with the foot laterally rotated and resents any attempt at passive movement.

In order to reduce the fracture it is necessary to bring the lower fragment into line with the upper by placing it in wide abduction and acute flexion. The limb is then immobilized in this position. The alternative method is to fix the fragments internally by the use of an intramedullary nail. Although the conservative method is quite practicable it is a nuisance for the patient and the nursing staff because the limb has to be so far out of bed. Intramedullary nailing is the method of choice for this fracture because it ensures that there will be no further displacement of the fragments after accurate reduction and the limb can be cradled comfortably in a Thomas's splint in the ordinary position. If the method of traction be used, it is better to employ skeletal traction by a Steinmann pin through the tibia at the level of the tibial tubercle because rotation of the limb can be controlled, and the amount of traction required may exceed the 14 lbs which is all that skin traction can be expected to tolerate. The high degree of flexion of the limb will obviate the need to raise the foot of the bed for counter traction. Immobilization is to be continued for 12 weeks and no weight bearing is allowed for a further 8 weeks but during this second period the patient begins walking with the aid of crutches and regains full joint movements.

(*b*) FRACTURES OF THE MID-SHAFT FEMUR. This is a common fracture in adults and children. The indirect violence from falling gives a spiral fracture or a longitudinal fracture (which is really a transverse fracture with longitudinal splits and cracks amounting to comminution) A clean transverse fracture is caused by an angulation or shearing force In all the complete fractures there is overlap and the transverse fracture will be accompanied by backward tilting of the lower fragment which is also externally rotated by the weight of the limb

If there be any displacement of the fragments the fracture must first be properly reduced under anaesthesia by manipulation The method of immobilization is then a matter of choice In Great Britain splintage and traction are favoured but on the continent the plaster spica holds pride of place. For children and adults whose reduced fractures are stable or originally had minimal displacement, fixed traction in a Thomas bed knee splint with the use of adhesive strapping on the skin is ideal (Fig. 31). The splint must be slung from a Balkan beam to help the patient to move about the bed and to facilitate nursing without any risk of disturbing the fragments of the femur The foot of the bed must be raised so that the body will supply a counter pull to the weight

traction on the end of the splint. The position of the femoral fragments must be checked radiographically during the first fortnight and then at about monthly intervals until union is complete It will probably be possible to discard the splint for this favourable type of fracture after 7 or 8 weeks in children but in adults the femur must be fixed for 10 weeks. Clinically union is estimated by testing the bone for firmness and the absence of pain at the fracture site when it is subjected to stress. The radiographs must show some callus formation although young callus is not entirely radio-opaque After union, knee movements can be started and the patient may begin walking with the aid of crutches but without any weight bearing on the injured limb Walking calipers are to be avoided because they are not certain to be weight bearing unless they are patten-ended. A comfortable caliper is by definition unlikely to bypass body weight and merely adds its own weight to the end of the limb and hence increases the angulatory and torsional stresses at the fracture site with the risk that the injured bone will bend.

When the reduction of the fracture is not stable and a weight greater than 10 lbs is required to maintain leg length, then balanced skeletal traction is the best method to employ this is applied through a Steinmann pin at the level of the tibial tubercle. The limb is placed in a Thomas splint with the addition of a Pearson knee flexion attachment (Fig. 33) which enables a pull to be maintained in the long axis of the femur whilst knee movements can take place Some form of rider between the traction cords and the pin is essential in order to prevent rotation of the pin in the tibia during joint movements and thus to avoid infection of the pin track in the bone. The management is similar to that for fixed traction but there will be the advantage that some degree of movement of the knee will already be present when the splint is discarded Whatever form of traction or fixation is used some stiffness of the knee may ensue and the degree of restriction of movement will vary with the distance of the fracture from the knee joint and the amount of surgical treatment to which the fracture site and its related structures have been subjected.

Open reduction and internal fixation of fractures of the femoral shaft is to be reserved for patients in whom closed manipulation has failed, those who have multiple fractures or a dislocated hip (in whom rigid fixation of the fractured femur will contribute materially to the management of the other fractures and injuries) and those who are preternaturally restless because of head injury alcoholism, or mental derangement. Whenever possible the open reduction of the fracture is carried out with the limb fixed on the Thomas splint in the majority of patients no form of internal fixation is required. In the restless patient it is best to insert an intramedullary nail. The use of plates and screws is to be deprecated because they delay union by tending to hold the absorbing ends of the fragments apart, they promote adhesions of the quadriceps to the front of the femur and so encourage stiffness of the knee. The intramedullary nail is not indicated for any fracture below the mid point of the femoral shaft because in the lower half of the bone the intramedullary canal widens and consequently renders the fixation of the nail less secure.

(c) Supracondylar Fractures of the Femur. In this fracture the small distal fragment is sharply flexed by the gastrocnemius muscle and may even injure the popliteal artery Failure to restore alignment will yield a genu recurvatum. After manipulation the limb is immobilized on a Thomas splint with Pearson knee flexion attachment and balanced skeletal tibial traction. Additional skeletal traction in the distal fragment in

an upward direction ought never to be required and its use will materially increase the likelihood of a stiff knee Immobilization must be continued for at least 12 weeks or even more because earlier movements intended for the knee are far more inclined to take place at the fracture site. Some residual stiffness of the knee is almost the rule.

(*d*) FRACTURES OF THE FEMORAL CONDYLES. These fractures tend to occur in older people in the form of a T or Y which separates the two condyles from each other and from the femoral shaft. One condyle only may be broken off and displaced upwards giving a genu valgum if it be the lateral condyle and a genu varum if the medial condyle Skeletal traction on a Thomas splint with manual compression of the displaced fragments is often sufficient to achieve satisfactory reduction If the restoration of the joint surface be unsatisfactory then open reduction and fixation of the condyles with screws is required.

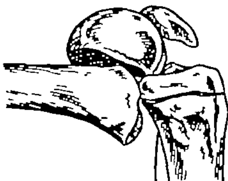


FIG. 72. Separation of the lower epiphysis of the femur

(*e*) SEPARATION OF THE LOWER FEMORAL EPIPHYSIS. The epiphysis is usually separated by a violent hyperextension force applied to the knee as in catching the foot in the spokes of a rotating wheel. The epiphysis travels forwards and upwards (Fig. 72) and the displaced lower end of the diaphysis is held down by the spasm of the gastrocnemius which is attached to its lower end. Tibial traction and flexion of the knee to a right angle will reduce the displacement and the reduction is easily maintained in this position of the knee by applying a plaster for 8 weeks.

(27) Knee

(*a*) FRACTURES OF THE PATELLA. A direct blow on the patella can cause such damage to the opposing articular surfaces of the patella and femoral condyles and the anterior capsule of the joint that a permanent disability will ensue. A transverse fracture of the patella can be produced by indirect or direct violence but the displacement of the fragments and the concomitant injury to the lateral expansions and the whole extensor apparatus will depend on whether the patient was moving at the time of the accident. A transverse fracture usually occurs in middle-aged people and the extensor apparatus is torn. The consequent fall to the ground may lacerate the knee and convert a closed into an open fracture. There is always a large hæmarthrosis of the knee and the gap between the fragments of the patella is easily palpable because the quadriceps draws the upper fragment proximally Active extension of the knee is not possible in the presence of a wide rent in the extensor expansion. Radiographs are required to estimate the degree of comminution of the fracture. Operative treatment is required for all patellar fractures except transverse or stellate cracks without displacement and it must not be delayed. Even when conservative treatment can be practised it is advisable to aspirate the effusion and blood in the knee and to apply a compression bandage to limit any further swelling. A plaster cylinder is then worn for 4 weeks so that first leg raising exercises and later walking can be started without fear of any ill to the joint. A transverse

fracture commonly splits the patella into approximately two equal fragments and an attempt must be made to restore the normal anatomy by accurate open reduction and fixation with a stainless steel screw placed vertically A transverse skin incision gives the best exposure of the tears in the extensor apparatus which must be repaired. Skin sutures may be removed in the second week and then a plaster cylinder worn for a month. Sometimes the polar fragment is very small and is best excised and the large patellar fragment left in place after repair of the torn extensor expansion. For comminuted fractures and open fractures it is necessary to excise the patella. Although this method of treatment yields the best restoration of function in such badly injured knees, there may be loss of the last 10-15 degrees of active extension because of the loss of the pulley action of the patella which causes the quadriceps tendon to stand away from the femur

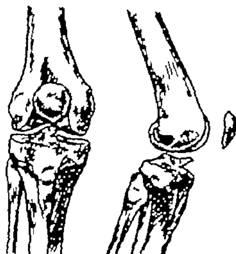


FIG. 73. Fracture of the tibial spine.

In youths the ligamentum patellæ may be ruptured and must be sutured. In children the tibial apophysis may be avulsed and, if not replaceable by manipulation, must be sutured into position. Traumatic dislocation of the patella is very uncommon but may result from a blow on the medial side of the bone which ruptures the medial capsule of the knee and the attachment of the vastus medialis to the patella. The soft tissue tears must be surgically repaired if recurrent dislocation of the patella is to be avoided.

(b) FRACTURE OF THE TIBIAL SPINE. This is caused by a direct blow on the front of the flexed knee which forces the femur backwards on the tibial head. The injury most often occurs in the adolescent and is commonly missed because the clinical evidence of cruciate ligament laxity may not be detectable until the effusion into the joint has been aspirated or spontaneously absorbed. Aspiration of the knee and examination of the antero-posterior mobility of the tibial head ought always to be done when an intra articular fracture of the knee is suspected. Radiographs will show avulsion of a fragment of bone from the centre of the tibial plateau (Fig. 73). The fragment can usually be replaced by fully extending the knee and fixed by a toe to groin plaster for 6 weeks. If reposition of the fragment be not sufficiently accurate by manipulation then open

reduction is required and, if essential, fixation with a suture taken out through drill holes in the bone to the front of the tibia.

(c) FRACTURES OF THE TIBIAL PLATEAU These are common fractures and are serious injuries which often leave a considerable residual disability. They are caused by a direct force from above when falling from a height or by forced abduction or adduction of the knee. Varus strains of the knee are not common because of the protection of the other lower limb and therefore fractures of the medial tibial tuberosity are rare but are treated in a similar fashion to the more common fractures of the lateral tibial condyle. Compression fractures caused by force applied from above tend to split the lateral tibial

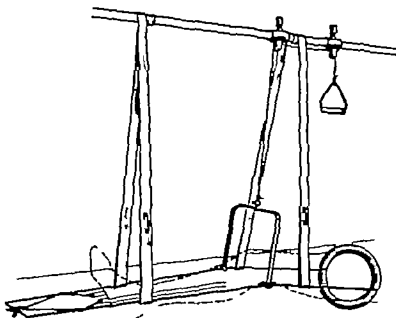


FIG. 74. Fisk splint.

condyle longitudinally in the sagittal plane causing the outer fragment to sink down for a small distance but usually there is no comminution of the articular surface. There is likely to be a simultaneous injury to the medial and central ligaments of the knee and certainly a large effusion and haemarthrosis with extravasation of blood into the soft tissues. The joint must be aspirated and then lateral instability of the joint may be demonstrable. A compression bandage is applied to control joint swelling and skeletal traction and a Fisk splint (Fig. 74) are used if the displacement of the fragment of the lateral tibial condyle is only minimal. By this means the knee can be kept moving passively and quadriceps exercises and active knee flexion can then be added. Weight bearing ought not to be allowed for 12 weeks but once a good range of knee movement is obtained ambulation with the aid of crutches may be encouraged. If the lateral tibial fragment is driven down or tilted then its accurate reposition is essential or a late valgus deformity of the knee will supervene. When closed reduction has failed it may be possible, through a small skin exposure, to lever up the fragment and fix it by lateral compression. Internal fixation is generally to be avoided, as well as immobilization of the knee in

to which it provides an attachment. The long lower fragment is drawn upwards and backwards by the posterior tibial muscles In consequence of the combined muscle action on both fragments backward angulation of the fracture must occur The fracture is usually open and comminuted and there is great risk of injury to the main blood vessels of the leg as they pass beneath the origin of soleus. Moreover the vessels at this site are especially vulnerable and there is a deficiency of collateral circulation which increases the risk of ischæmia of the leg. Reduction of the fracture is not difficult and union is to be expected but redisplacement of the fragments and consequent malunion is equally to be feared. The proximity of the fracture to the knee joint is bound to give a high incidence of strain or rupture of the knee ligaments which will add to the instability of any genu recurvatum that may ensue from persistent posterior angulation of the fracture. After reduction it is best to transfix both the upper and the lower fragment with a Steinmann pin and to incorporate each pin in a plaster extending from the groin to the toes for 12 weeks.

(*b*) FRACTURE OF THE SHAFT OF THE TIBIA. This fracture usually occurs at the level of the middle of the shaft of the bone at the point of direct impact and it is a transverse fracture which may be comminuted. A frequent variant is the butterfly fracture which is the transverse fracture with a third fragment. The displacement of the fragments is small but, because of the subcutaneous situation, it is, in common with all fractures of the leg bones, often an open fracture. In the child there is just local tenderness but in the adult there is also obvious trauma of the skin. In adults and children twisting injuries may cause a spiral fracture of the tibia and here also there tends to be little displacement of the fragments though they are often angulated. The leg is immobilized in a plaster extending above the knee and any persistent angulation is corrected by wedging the plaster Plaster protection is required for 8 weeks at least or longer if union is still considered to be unsound. Sometimes union is delayed by the effect of the intact fibula as a splint in preventing close apposition of the absorbing bone ends of the fractured tibia. Excision of a piece of fibula will permit the tibial fragments to be compressed when the patient walks wearing a plaster on the leg and union will then be quickly promoted.

(*c*) FRACTURE OF THE TIBIA AND FIBULA. These are very common fractures in children and adults. They are usually spiral fractures at the level of the middle of the tibial shaft and the upper third of the fibula as a result of a twisting force applied when the foot is fixed to the ground. The lower fragments shift laterally rotate externally because of the weight of the foot, and the fragments overlap. Rotation and overlap are easily corrected by skeletal traction but the reduction of the lateral shift is often difficult and, as in all leg fractures, the fragments are prone to slip out of position even after satisfactory reduction has been achieved. The problem of successful treatment is really that of fixing the reduced fragments. In the oblique fracture transfixion with a screw is the ideal method because the screw is placed after accurate open reduction of the fracture and rapid union ensues without any danger of slipping of the fragment (Fig. 76) Walking 6 weeks after operation may be permitted if the leg is protected with a plaster extending above the knee. When the fracture is not suitable for screw fixation (as for instance in the presence of gross comminution), the fracture is transverse or double so that there is a separate middle fragment (Fig. 77), then manipulation of the fracture under skeletal traction through the lower end of the tibia is the method of choice. Redisplacement of the

fragments is best avoided by transfixing the upper fragment with another Steinmann pin and by incorporating both pins in the groin to toe plaster that is applied with the patient's knee a little flexed. *Plate and screw fixation* may be indicated to control the middle fragment. Leg plasters applied without pin fixation of the fragments require to be reapplied after 3 weeks because of the shrinkage of the previously swollen limb and the

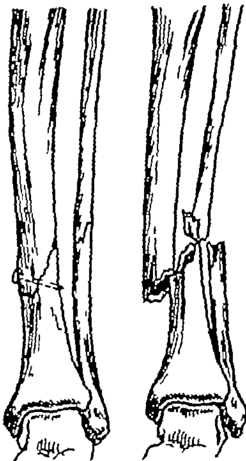


FIG. 76. Screw fixation of fractures of the tibia and fibula.

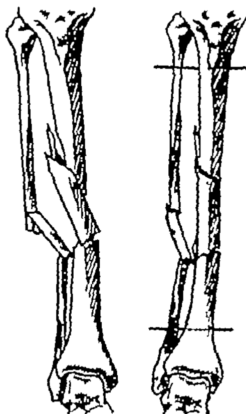


FIG. 77 Double fracture of the tibia and fibula and two pin fixation.

consequent danger that the fragments will redisplace. Pins may be removed after 6 weeks and a walking plaster applied with very little risk of disturbing the position of the fragments. Continuous traction applied to the tibia is never justified and will always produce distraction and delayed union. Pin traction through the calcaneum for reduction is to be avoided because it promotes a calcaneus deformity and a secondary claw foot and rigidity and clawing of the toes. Calcaneal traction is only to be used for open fractures in which the lower tibial fragment is too short to keep the traction pin clear of the wound. *Minor degrees of mal-alignment can be corrected adequately by wedging* the plaster (Fig. 78). Plaster immobilization will be required for at least twelve weeks and weight bearing is not allowed until clinical union of the fracture is judged to be sound.

Transverse fractures remain stable once the fragments are hitched on to one another but correct alignment and rotation must be obtained The need for internal fixation by plate and screws ought to be very infrequent and the method has its best application as a means of fixing fragments after resection for non-union so that cancellous bone chips can be used for the graft in preference to cortical bone Union of tibial fractures tends to be

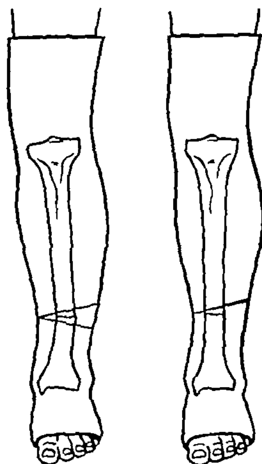


FIG. 78 Wedging of plaster to correct angulation.

slow because of the relatively poor blood supply of the lower tibial fragment and any measure such as plating or continuous skeletal traction is bound to hinder union still more, even up to the point of established non-union

(29) Ankle

The factor which is common to all ankle injuries is the relative fixation of the talus (talar fixation factor) either because the foot is firmly planted on the ground or else the foot takes the first impact of a fall from a height. The external forces applied to the ankle are torsion, angulation, and sideways shear according to the direction in which the body weight is thrown. These forces are responsible for rupture of the ankle ligaments, avulsion fractures, and hinge fractures. The internal force is supplied by the talus

reasonably well restored, there is every likelihood that chronic pain and disability of some degree will remain. Failure to reconstitute the subtalar joint will leave a stiff painful foot which may not be entirely relieved by subtalar arthrodesis.

Fractures not implicating the subtalar joint include an avulsion fracture of the insertion of the tendo Achillis, an avulsion fracture of the attachment of the plantar fascia, a vertical fracture of the tuberosity and, very rarely a beak fracture along the tuberosity above the insertion of the tendo Achillis The first fracture needs an open operation to replace the insertion of the tendo Achillis and fixation of the fragment with a screw (Fig. 82) plaster is applied from above the knee to the toes for eight weeks in order to protect the fragment from coming adrift. The beak fracture can usually be adequately reduced by manipulation but the leg and foot must be immobilized in a below

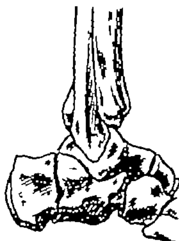


FIG. 83. Vertical fracture of the calcaneum.

knee plaster for 6 weeks to avoid redisplacement of the fragment. The vertical fracture often has minimal displacement (Fig. 83) and, after the contusion and swelling have subsided early walking on the toes of the affected foot with the aid of a stick is recommended displacement of the fracture is readily corrected by manipulation and then a below knee plaster is advisable for 6 weeks.

All the other fractures of the calcaneum are compression fractures and vary only in the amount of displacement which occurs in direct relationship to the power of the crushing force. The fractures may be without displacement and not including the subtalar joint and, therefore, they are treated in the manner indicated for the first group. Of the fractures which do affect the subtalar joint the more rare tongue depression fracture is produced by transference of the crushing force from the body weight through the tibia to a spur on the talus, which is driven into the angle between the anterior and posterior subtalar articular surfaces, to depress a long lever of bone (Fig. 84) In the common joint depression fracture the calcaneum subsides under the subtalar articular surface and the tuberosity of the calcaneum is displaced upwards. The angle depicted on a lateral radiograph between a line along the upper surface of the calcaneal tuberosity and the projection backwards of a line along the subtalar articular surface is called the

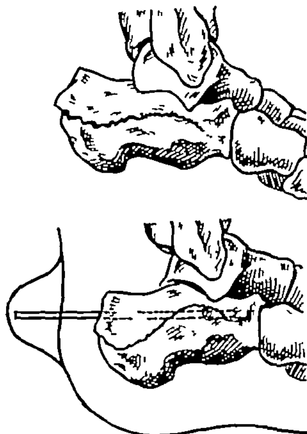


Fig. 84 Tongue depression fracture of the calcaneum.

salient angle and its value is normally between 30 and 40 degrees (Fig. 85) Any displacement upwards of the calcaneal tuberosity or any subsidence of the subtalar articular surface will reduce the size of the salient angle or even reverse it (Fig. 86). Any alteration



Fig. 85. Normal salient angle of the calcaneum.

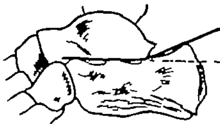


Fig. 86. Loss of the salient angle in joint depression fracture of the calcaneum.

in the value of the salient angle is, therefore, a measure of the degree of displacement and, after treatment, it is a measure of the degree of reduction obtained. Upward displacement of the calcaneal tuberosity is tantamount to elongation of the tendo Achillis and will permit excessive dorsiflexion of the foot and will cause loss of spring in the

action of the calf muscles Crushing of the calcaneum reduces the height of the bone and increases its width and is associated with either inversion or eversion according to which side of the bone is the more affected. In young and middle-aged people it is advisable to correct the upward displacement of the calcaneal tuberosity in order to overcome the insufficiency of action in the calf muscles. Open reduction of the fracture is required and the fragments are transfixed with a Steinmann pin which is left projecting out of the back of the heel and is incorporated in a "sabot" plaster which leaves the toes and ankle free to move (Fig. 87) The pin is removed after 5 weeks and a below knee plaster is applied for a further month for the joint depression fracture After removal of the pin in tongue depression fractures, no further plaster immobilization is needed but non-weight bearing exercises are given for 3 weeks before ordinary walking is allowed. In people over 60 years old in whom crush injuries of the calcaneum have disrupted the subtalar articular surface it is best to rest the feet in bed until the initial swelling and pain have subsided and then to start non-weight bearing movements. Plaster immobilization for such patients would only produce a stiff foot whereas a mobile foot, even when the primary deformity of the fracture has been accepted, is of much greater functional use



FIG. 87 "Sabot" plaster

(*b*) FRACTURE OF THE NECK OF THE TALUS. This fracture occurs in forced dorsiflexion of the foot and the neck of the talus is split across by the anterior margin of the tibia. Formerly a specific injury of aviation pilots, it has again become very rare since the advent of jet aircraft. The force required to displace the talar fragment is often enough to produce dislocation of the posterior portion of the subtalar joint. Reduction is achieved by plantar flexion of the foot and any associated subtalar dislocation can only be kept reduced by immobilizing the foot in full plantar flexion for 3 months.

(*c*) SUBTALAR DISLOCATION. Ordinarily dislocation of the subtalar joint is caused by forced inversion of the foot which ruptures the lateral ligaments of the ankle. If the inverting force continue and the foot be simultaneously plantar flexed the interosseous ligaments between the talus and calcaneum will rupture and the calcaneum will dislocate inwards leaving the talus still in place in the ankle mortise. If all the ligaments be ruptured the talus will be totally dislocated and will come to lie across the front of the ankle joint. A subtalar dislocation is reduced by abducting and everting the foot during plantar flexion and the foot is then immobilized in a below knee plaster for 6 weeks but walking is permitted. The totally dislocated talus must be replaced by pressing on it with the thumbs whilst the foot is forcibly inverted and plantar flexed. If additional power of inversion of the calcaneum is required the bone may be transfixed with a Steinmann pin and then traction can be applied to open up the gap to contain the talus. In the event of failure open reduction must be performed.

(*d*) FRACTURE-DISLOCATION OF THE FOOT Apart from dorsal flake fractures and avulsion of the tuberosity fracture of the navicular alone infrequently occurs. The large dorsal fragment can be manipulated into position but redisplaces easily and is likely to die. After reduction the foot must be immobilized in a below knee plaster and

no weight bearing allowed until sound, painless fibrous ankylosis has occurred or else arthrodesis will be required. Fracture-dislocation of the mid tarsal joint may be caused by forced abduction or adduction of the forefoot but most commonly by severe crushing of the foot. Reduction by manipulation is usually satisfactory except for crush injuries and for these mid tarsal arthrodesis will probably be needed because of pain. The reduced mid tarsal dislocation must be immobilized in plaster of the foot for 3 months Fracture-dislocation of the tarso-metatarsal joint is caused by forced pronation of the forefoot and is often associated with vascular injury with a consequent risk of gangrene of the foot. After manipulative reduction the foot must be immobilized in a below knee plaster for 2 months and weight bearing is not allowed.

(*e*) FRACTURES OF THE METATARSALS AND TOES. Fractures of the metatarsal necks are the most important because of the difficulty of replacing the metatarsal heads and of the disability during walking if reduction fails. Union occurs if the foot be immobilized in plaster but if the metatarsal heads cause pain in walking they may have to be excised. Fractures of the phalanges of the smaller toes tend to angulate and after union the toes are clawed. Fracture of the hallux shows very little displacement and is easily controlled by the application of a gauze and collodion dressing until union occurs

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CHAPTER V

MAL-UNION

ROBERT ROAF

INTRODUCTION AND DEFINITIONS

MAL-UNION is defined as union in bad position; the question is what is meant by "bad." The body can tolerate considerable deviations from anatomical perfection, especially in childhood when further growth will usually correct even considerable deformities. In some situations, deformity does not interfere with function. In particular, in the upper limb, shortening and even considerable angulation are compatible with normal function and good appearance. In practice, the chief problem in treating fractures is to know when the position of the bones is "good enough" after simple closed reduction or when further more complicated methods of treatment are needed to improve the position in the interests of function. We can define mal-union as union in a position which will lead either to permanent impairment of function or marked cosmetic blemish.

Displacement at the site of a fracture can be:

(1) Longitudinal—(*a*) shortening (Fig. 88)
(*b*) lengthening (Fig. 89)

(2) Rotational—(*a*) external (Fig. 90)
(*b*) internal.

(3) Lateral angulation—(*a*) Varus bowing (Fig. 91)
(*b*) Valgus bowing.

(4) Antero-posterior angulation—(*a*) forward bowing (Fig. 92)
(*b*) backward bowing.

(5) Lateral or antero-posterior displacement (Fig. 93).

These descriptions are self-evident; clearly various displacements can be combined, indeed shortening implies some degree of lateral displacement.

Deformity may be primary or secondary. Primary deformity is deformity due either to failure to reduce or failure to retain the fragments in good position. Secondary deformity is deformity arising at a later date, due to disturbance of epiphyseal growth.

Treatment. The treatment of mal-union may be conservative or operative.

Conservative

In certain situations, e.g. the humerus, quite considerable overlap, angulation and rotation are compatible with good function and appearance. In such cases, the movements of the joints above or below the mal-union compensate for the deformity and clearly ball-and-socket joints have greater powers of compensation than simple hinge joints which can compensate for antero-posterior but not for lateral angulation. In the lower limb, it may be necessary to compensate for shortening by adding a "raise" to one shoe; this may be combined with taking off a thickness from the heel of the shoe of the longer

Fig. 90. Rotational displacement.

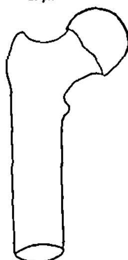


Fig. 89 Displacement with lengthening.

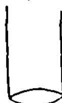
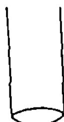


Fig. 88. Displacement with shortening.









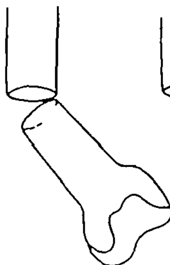


Fig. 91 Lateral angulation.



Fig. 92. Antero-posterior angulation.

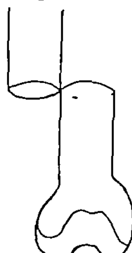


Fig. 93 Lateral displacement.

leg. In addition, if the hips are fully mobile, pelvic inclination can compensate for up to 1½ in. of leg inequality

Mal-union of the tibia or femur may throw undue strain on the knee or ankle joint and cause pain and instability If operation is contra-indicated as, for instance, in elderly people with Paget s disease, a supporting splint such as a walking caliper may be required for the relief of pain and instability

Operative

Spur Removal. The simplest type of operation is to remove the protruding spike of bone where this is either causing pain, pressing on the skin, nerves or blood vessels or is a major cosmetic blemish. In general, a semi-circular incision should be used to approach such a spike of bone and due regard should be paid to Lange s lines and the risk of cheloid development in the operation scar

Such operations are very simple and therefore attractive, especially to young surgeons but they should not be undertaken lightly particularly if they are done for cosmetic reasons. The surgeon should be sure that the scar will not be even more unsightly than the spike.

Osteotomy

Correction of shortening, angulation or rotation deformity may be achieved by dividing the bone (osteotomy) and placing the two fragments of bone in the correct position. The osteotomy may be linear transverse, linear-oblique, cuneiform, V-shaped or incomplete (see below).

In general, it is easy to divide a bone but, after the osteotomy various complications may develop

(1) It may be hard to hold the fragments in good alignment even with a skilfully applied plaster cast or the application of a splint with continuous traction, such as a Thomas splint. In some circumstances, it may be necessary to use internal fixation to hold the bone ends in alignment.

(2) Correction of the deformity may either stretch or put pressure on the skin, nerves or blood vessels, leading to serious complications.

(3) The two pieces of bone may not unite. This is specially likely to happen either where there is displacement of the bone ends with lack of apposition or distraction of the bone ends as, for instance, where a shortened bone is being lengthened.

(4) The osteotomy and correction of deformity may have an adverse effect on the adjacent muscles and joints.

For these reasons, before embarking on the operative correction of a mal-union, the surgeon should always satisfy himself that correction is really needed and should consider carefully the best type of osteotomy and the best way of controlling the fragments after the bone has been divided.

Transverse Osteotomy (Figs. 94 and 95)

This is the simplest osteotomy to perform. The bone is exposed, the periosteum is cut longitudinally and raised working sub-periosteally the bone can now be divided either with an osteotome or a keyhole saw The classical osteotomy of the first type is Mac ewen s supracondylar osteotomy of the femur for knock knee which is performed from the medial aspect the cut in the bone is made one and a half inches above the epiphyseal

line and the bone is three-quarters divided with the osteotome. Division of the bone is then completed by manual osteoclasis (Fig. 96)

The classical operation of the second type is Jones osteotomy for knock knee in which the femur is divided at the same level but from the outer side, using a Jones saw Again, division of the bone is completed by manual osteoclasis.

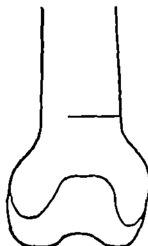


FIG. 94. Transverse osteotomy (Jones).

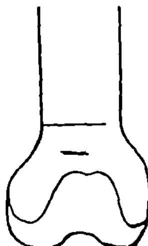


FIG. 95. Transverse osteotomy (Macewen).

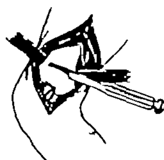


FIG. 96. Macewen's osteotomy

Following this, the fragments are fixed by applying either a plaster of Paris spica or a Thomas splint (Figs. 97 and 98)

Although these classical operations have yielded good results in many thousands of patients, certain problems can arise. In particular control of the small distal fragment of the femur is difficult and both lateral displacement and backward angulation at the



FIG. 97 Plaster spica with wedge cut in plaster for correction of angulation.

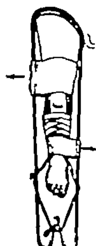


FIG. 98 Thomas splint applied after supra-condylar osteotomy for knock knee. (Note bands around ankle and around thigh.)

osteotomy site may occur In addition, if the deformity is bilateral, it may be hard to ensure that both legs are identical after a bilateral osteotomy For these reasons, a number of refinements have been suggested and used. It is, however important that the *surgeon should understand and thoroughly master the simple classical operations before* embarking on the more complicated modifications which have both advantages and disadvantages—always remembering that the pen is mightier than the osteotome, and it is easier to draw a complicated osteotomy on paper than to achieve it in the operating theatre—especially as bone has a tendency to splinter crack or fissure in unintended directions.

Oblique linear osteotomy is sometimes used to correct deformity (Fig. 99). Its advantages are—(1) quicker union, and (2) less risk of the bone ends becoming separated. Its disadvantage is that it is very hard to obtain much correction of deformity and, in particular it is almost impossible to correct rotation deformity



Fig. 99 Oblique osteotomy



Fig. 100. V-osteotomy



Fig. 101 Wedge osteotomy

A development of the oblique osteotomy is the V-osteotomy (Fig. 100) This has the advantage of maintaining excellent contact between the bone ends. The disadvantages are that the deformity can only be corrected in one plane and that it is technically difficult it is comparatively easy to cut a V in the "near" cortex but very hard to cut a similar V in the "opposite" cortex. A series of drill holes must be made in the shape of a V and these are joined with a fine osteotome. Even when this is done very carefully the opposite cortex frequently splits in a different pattern.

In cuneiform osteotomy (Fig. 101) a wedge of bone is excised with its base at the convexity of the bowing. This is an excellent way of correcting deformity in one dimension and avoids the risk of excessive tension or pressure on soft tissues

In certain special situations, it is convenient to fashion a spike on the cortex of one fragment which is impacted into the cancellous tissue of the other fragments. This is useful where it is desired to maintain the fragments in close apposition but there is little natural stability—its chief field of application is in performing an intertrochanteric displacement osteotomy of the femur (Fig. 102 (*a*) and (*b*))

Probably the best way of correcting deformity with the minimum risk of the fragments becoming displaced is the method of osteotomy-osteoclasis. In essentials, the technique is to excise a wedge of bone but leave the cortex on the opposite side undivided. This intact portion of cortex is now drilled in several places until it becomes slightly flexible.

The gap in the bone, due to removal of the wedge is *now* packed with bone chips and a plaster cast is applied to the limb A fortnight later a wedge is cut out of the plaster at the site of the convexity of the deformity and the bone is then gently bent to the correct

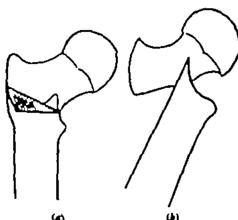


Fig. 102. Spike osteotomy for sub-trochanteric displacement osteotomy (*a*) Before. (*b*) After displacement.

position and the plaster repaired so as to hold the limb in this position. By this technique, *there is no risk of the bone ends becoming displaced or separated from one another* and bony union occurs very quickly (Figs. 103 104 105 and 106)

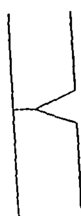


Fig. 103. Osteotomy-osteoclasis.

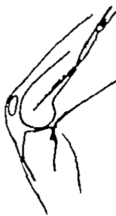


Fig. 104 Osteotomy-osteoclasis for knock knee. Skin incision

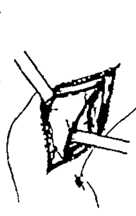


Fig. 105 Osteotomy-osteoclasis for knock knee. Excision of wedge of bone.

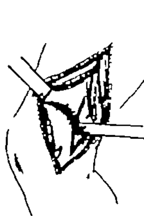


Fig. 106. Osteotomy-osteoclasis for knock knee. Wedge of bone removed, opposite cortex drilled and small bone chips replaced in gap in the bone.

Unreduced Dislocations

Generally speaking, the sooner a dislocation is reduced, the quicker and *more com* plete recovery is likely to be. The longer a joint is dislocated, the greater will be both the degenerative changes in the articular cartilage and the amount of peri articular fibrosis

The practical question which the surgeon has to decide, when confronted with an old-standing dislocation, is whether to attempt a closed reduction, or an open reduction, or to leave the joint dislocated and attempt to improve function by trying to create a false joint—if necessary improving function and appearance by either a "sham reduction" or a corrective osteotomy In every case, four factors must be considered

(1) The joint involved.
(2) The age of the patient.
(3) The length of time since dislocation.
(4) The presence or absence of neuro-vascular complications.

At one extreme, a dislocated hip in a child with a sciatic nerve lesion should certainly be reduced by open operation, even if the dislocation is several months old. Conversely it would be wise to leave alone a dislocated elbow or shoulder (even a month old) in an elderly person, provided there was no pressure on major arteries or nerves.

The special problems of each major joint will be considered separately

Acromio-Clavicular or Sterno-Clavicular Joints. Usually old-standing dislocations of these joints should be left alone and treated by active exercises, occasionally partial or complete removal of the clavicle may be performed, either for persistent pain or cosmetic reasons but such operations should never be undertaken lightly and the results are seldom entirely satisfactory

Shoulder Anterior Dislocation

It is convenient to consider young and old patients separately the distinction is not always clear cut and depends more on the patients outlook and activities than on his actual chronological age A patient may be said to be "young" if he insists on leading an active life and uses his arm for vigorous manual work.

"Young" Patients. Up to four weeks from the dislocation, closed reduction may be attempted. First rate anæsthesia with complete relaxation is a *sine qua non*. If the first attempt fails, it is justifiable to try once again after a few days continuous traction. If closed reduction does not succeed, it may be justifiable to perform an open reduction provided the patient understands that the result will probably be a stiff and painful shoulder which may later require an arthrodesis. Nevertheless, this is the patient s best chance of obtaining a strong normal-looking shoulder which can be used for strenuous activity

Old Patients. Not more than two attempts at closed reduction may be tried up to three weeks from injury Special care must be taken not to fracture the humerus which is usually brittle and osteo-porotic in these cases. If these fail, it is usually best to advise the patient to accept the disability and to try to improve strength and range of movement by active exercises. Continuous traction is usually inadvisable in the elderly open reduction is only indicated if the head of the humerus presses on the neuro-vascular bundle.

Posterior Dislocation

It is often hard to recognize a posterior dislocation, especially in fat people. Even an ordinary antero-posterior X-ray may fail to reveal the condition clearly If in doubt, a vertical or axillary view of the shoulder should be taken. If the dislocation is not recognized, management is essentially the same as for an unreduced anterior dislocation though persistent pain is more likely and arthrodesis is often required.

Recurrent Anterior Dislocation of the Shoulder

In the usual anterior dislocation, either the glenoid labrum is detached from the rim of the glenoid cavity or the anterior part of the capsule of the shoulder joint is torn Occasionally the lesion fails to heal either due to the inherent avascularity of the cartilagenous glenoid labrum or to inadequate immobilization of the torn capsule. In such cases, recurrent dislocations will occur The treatment is either to repair the defect by operation (Bankart) or create a buttress in front of the shoulder either by fixing a bone graft to the edge of the glenoid cavity or reefing the capsule and subscapularis muscle so as to create a barrier to further redislocation (Putti Platt).

Bankart s Operation

A 7 in incision is made in the general line of the delto-pectoral groove a straight incision in the direct line of the groove is apt to heal with keloid formation accordingly many surgeons prefer to make a curved or s-shaped incision and also give post-operative irradiation. The delto-pectoral groove is then defined and these two muscles separated. The joint origin of the coraco-brachialis and the short head of the biceps is identified and the tip of the coracoid process to which they are attached is divided and, with the attached muscles, is pulled down. The capsule is divided parallel to and half an inch away from the anterior glenoid margin. The redundant weak capsule and/or the torn glenoid labrum are now removed, the bone anterior to the glenoid articular surface is rawed and the capsule is firmly fixed to the raw bone, either by drilling holes in the bone or more easily with three screws. This part of the operation is made much easier if the head of the humerus is held out of the way with a Bankart skid. The wound is now closed in layers and the humerus held to the side in internal rotation for six weeks.

Recurrent Posterior Dislocation of the Shoulder

Rarely the head of the humerus may be liable to recurrent posterior displacements—more correctly termed a subluxation than a dislocation. The condition may appear spontaneously or following a minor injury The condition often causes relatively little disability but, if there is significant disability the condition can be cured by fixing a bone graft to the posterior rim of the glenoid cavity (Figs. 107 and 108)

Operative Treatment. An incision is made along the lower border of the spine of the scapula and posterior aspect of the acromion. The posterior fibres of the deltoid muscle and the infraspinatus muscle are separated from the bone. The posterior portion of the capsule of the shoulder joint is now seen. If redundant, it is plicated, a 5 in. × ¾ in × ½ in. cortical bone graft is now fixed to the under-surface of the spine of the scapula so that its outer end overlaps the shoulder joint and is flush with the posterior articular margin of the glenoid. The wound is now closed in layers and a plaster of Paris shoulder spica applied for three months.

Post Traumatic and 'Idiopathic' Stiffness of the Shoulder Rotator Cuff Lesions, Sub-acromial and Bicipital Syndromes

With the passing of time the capsule of the shoulder joint and the adjacent tendons (supraspinatus, infraspinatus, subscapularis, long head of biceps) undergo degenerative changes and become friable and brittle. As a result, even trivial injuries may lead to

After manipulation, regular active exercises are a necessity for success. In the early stages, these are usually painful and the patient requires assistance and encouragement. As a general rule, patients should stay in hospital for a few days after the manipulation.

Very occasionally arthrodesis is required for a persistently painful shoulder but the result is usually disappointing in patients over thirty years of age.

Elbow

It is well recognized that, following even a trivial injury the elbow is very apt to become stiff and that the tissues in front of the elbow are one of the most frequent sites for the development of myositis ossificans. Every hour that a dislocated elbow remains "out" makes the prognosis worse.

As a rough rule, it is usually inadvisable to attempt reduction if more than ten days have elapsed since the injury After that, it is usually better to perform a sham reduction" as advocated by Hugh Owen Thomas In this manœuvre the elbow is flexed to just above a right angle, the arm is placed in a collar and cuff and the patient is encouraged to perform active flexion movements. When he has regained a useful range of flexion and can hold the arm flexed, the collar and cuff is slowly lowered. The functional results of this procedure are usually surprisingly good.

Open reduction of a dislocated elbow almost inevitably results in a stiff and painful elbow and should only be done as a basis for a future arthrodesis after taking full account of the patient s work and recreations.

Recurrent Dislocation of the Elbow

Occasionally the elbow is the site of recurrent dislocation. This is always posterior and is due either to a shallow coronoid fossa secondary to a fracture of the coronoid process or to an unhealed tear or laxity of the anterior part of the capsule. The condition can be cured either by inserting a bone graft into the coronoid fossa or by reefing" and strengthening the capsule anteriorly

Head of Radius

The head of the radius may remain permanently dislocated as a result of (1) injury (nearly always associated with a fracture of the upper third of the shaft of the ulna—the combination is usually called a Monteggia fracture) (2) shortening of the ulna (3) as a congenital condition. Usually no treatment is required very occasionally if it is painful or restricting movement, the head of the radius may be removed, but this should never be done in children as subluxation of the inferior radio-ulnar joint may occur

Lower End of Ulna

This may be either dislocated posteriorly as a result of rupture of the triangular fibro-cartilage or inferiorly as a sequel to shortening of the radius. In both, the treatment is either to remove the lower end of the ulna or to perform a reconstructive operation. In the first type of lesion, the aim of reconstructive surgery is to make a new ligament binding the radius and ulna together In the second lesion, the ulna is shortened by a "Z" osteotomy

Carpal Semi-lunar

Occasionally a dislocation of the semi lunar bone is unrecognized the dislocation is always forwards and usually the displaced bone presses on the medial nerve and flexor tendons of the fingers The treatment of an established unreduced dislocation is to remove the displaced bone.

Other unreduced dislocations of the wrist, e.g. trans scaphoid peri semilunar—usually give rise to such disability that open reduction and arthrodesis are required

Old-standing dislocations of carpo-metacarpal joints usually give rise to relatively little disability but, if pain is persistent, open reduction and arthrodesis will be required.

Old-standing dislocations of the metacarpo-phalangeal and inter phalangeal joints of the fingers are usually best treated by partial or total amputation of the digit, if they cause pain

In the case of the thumb, open reduction and arthrodesis of the affected joint is usually the best treatment.

Spine

Excluding major neurological complications, unreduced fracture-dislocations of the spine give rise to three disabilities—deformity pain and stiffness.

Deformity is not usually serious and is best treated by attention to posture and developing "compensatory curves" above and below the site of the deformity

Pain is not usually a serious feature it is remarkable how little disability even gross displacement may cause. Most patients become pain free with assiduous performance of erector spinæ exercises, and if necessary wearing a supporting brace to prevent flexion strains. Occasionally pain is persistent if the patient is psychologically stable, arthrodesis restricted to the affected joints, will cure the pain

Stiffness is partly local and partly reflex. Local stiffness, i.e. loss of movement between two or three vertebræ is relatively insignificant, reflex stiffness is more widespread and disappears when the pain goes.

Hip

If a dislocated hip remains unreduced for more than four weeks, the probability is that the hip joint will become painful, stiff and arthritic if it is reduced. In young people, the best treatment is to attempt a closed reduction If this fails, it is usually necessary to perform an open reduction and arthrodesis. In older patients, or those who spend most of their life sitting or squatting, a sub-trochanteric osteotomy to correct flexion and adduction deformity is the best treatment and the functional result is usually surprisingly good. If the head of the femur is pressing on the sciatic nerve, either the head and neck of the femur should be removed, producing a pseudo-arthrosis, or an open reduction and arthrodesis should be performed. This latter is a major procedure and is only indicated in fit, young patients.

Patella

An unreduced traumatic dislocation of the patella is usually best treated by excision.

Knee, *Ankle* and Foot

In these joints, painless stability is essential, therefore open reduction and arthrodesis are required if such joints are painful or unstable after dislocation (Fig. 109 (*a*) and (*b*))



FIG. 109 (*a*) Unreduced fracture-dislocation of the ankle 20 years after original injury (*b*) After successful fusion of the ankle.

CHAPTER VI

BURNS

JOHN WATSON

GENERAL CONSIDERATIONS

A BURN may be defined as injury to the tissues of the body arising from exposure to any of the following agents

Heat.
Electrical conduction.
Chemicals.
Irradiation.

The frequency of burns throughout this country is not known with accuracy but the total number of burns severe enough to require hospital treatment was estimated by Colebrook in 1946 as approximately 100,000 annually of which between 20 000 and 30,000 required admission to hospital. In spite of the increasing complexity of industrial processes, domestic accidents occur roughly twice as frequently as industrial accidents and account for over 90 per cent of the fatalities, due mainly to the prevalence of open fires and to accidents with hot liquids. Apart from the economic cost to the community the annual toll of human suffering experienced both by the victims of severe burning and by their relatives cannot be evaluated. The proper management of these common injuries from the standpoint both of the magnitude of the overall problem and of the individual patient presents many difficulties. There is little doubt that both clinical and economic considerations are best served by the segregation of these patients into specialized units, equipped with the special facilities needed for their treatment, tuned to the fast tempo required in successful early management, and preferably forming part of the larger general hospitals.

The manner in which the accident occurs tends to produce burns of characteristic pattern, so that the injuries may be classified by the mode of their infliction, as follows

Flame Burns. Arising from contact of the skin with flame, these burns are usually caused by the clothing catching fire, and less commonly in accidents with inflammable liquids or in conflagrations. The severity is in some degree proportional to the inflammability of the clothing, and some protection is afforded by the undergarments if the burning outer clothing can be cast off sufficiently rapidly If the victim lies down, only the front or back of the body may be burned, and if the protective "fœtal" position is adopted, important skin areas in the joint flexion creases may be preserved. Usually there is an impulse to run and extensive deep circumferential burns of limbs and trunk arise. The face may escape other than superficial burning but the neck may be deeply burned as the flames lick upward round the chin. This type of injury is commonest in women and children, the aged and infirm, and is rarely a form of attempted suicide.

Contact Burns. Direct contact with a hot surface produces a localized burn the depth of which depends on the temperature and duration of contact, and to a lesser extent on

the thickness of the keratinized layers of the skin in the zone burned. Poor circulation in the involved skin may increase the liability of damage by failure to conduct away the heat applied (e.g. the hotwater bottle burn in the unconscious patient). These burns are usually superficial owing to prompt withdrawal, unless this is prevented by entanglement in machinery or by unconsciousness. The deepest and most destructive burns occur in epileptics, or in elderly people subject to attacks of unconsciousness from cardiovascular disease.

Flash Burns. Such burns are due to the explosion of inflammable gases usually petrol vapour or oxy-acetylene, the blowing-up of explosives, or the flash of an electric arc. There is exposure to intense heat of short duration, often so brief that ordinary clothing provides a measure of initial protection. The face and hands may thus be the only portions burned.

Scalds. Burning with hot liquids is mainly a domestic accident, from mishaps with cooking utensils and hot baths, and usually involves young children. Owing to rapid cooling of the liquid from evaporation, in the absence of actual immersion the destruction is often superficial although it may be widespread. Industrial accidents from escaping steam may cause deep and destructive damage. Splashing with molten metal, with its high initial temperature and capacity to retain heat for a long period may produce deep local destruction and if contact is made with the cornea may endanger sight involvement of large areas is uncommon unless the metal flows into the boots

Inhalation Burns. Damage to the air passages causing œdema of the larynx and respiratory obstruction, or an acute thermal tracheo-bronchitis, occurs as a complicating factor in burns of the face and neck. This type of injury merits separate consideration because it may form the essential lesion of sinister significance, while the surface burn may be quite limited and appear to carry no threat to survival. Inhalation burns are more likely to occur when steam rather than hot air has been inhaled, owing to the heat content of steam which is forty times greater per unit mass. Pulmonary complications also occur as a complication of burns sustained in confined spaces or conflagrations, from release of noxious gases (e g. oxides of nitrogen) absorption of carbon monoxide may also take place. Respiratory complications are always a source of anxiety in burn therapy and are responsible early or late, for a high proportion of fatal cases.

Friction Burns. These burns arise from contact with revolving belts, abrasive wheels, etc., or from cables which slip through the grasp. Usually local in distribution, the injury is as a rule complicated by soft tissue lacerations.

Chemical, Electrical, and Radiation Burns. The distinctive features of these injuries will be considered later

Assessment of the Severity of the Injury

The extent, depth, and site of the burn determine the severity of the injury in respect of risk to life, danger of loss of function, and duration of treatment.

Extent. Estimation of the burn in relation to the area of body surface involved provides within limitations a basis for initial assessment both of the severity of the systemic disturbance likely to occur and of the extent of constitutional treatment likely to be required for its mitigation. The extent, expressed as a percentage of total body area, may be calculated from Berkow's tables. Wallace (1951) has devised a simplified pictorial version by expressing the various zones of the body in terms of 9 per cent or multiples of

9 (Fig. 110) The chart is a useful aid to memory and its accuracy sufficient for clinical purposes. Due allowance must be made for the differing body proportions of infancy. A chart incorporated in the patient's case-notes, delineating the body outline, and on which the burn can be pictorially recorded, aids accuracy and saves much verbal description.

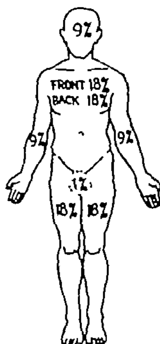


Fig. 110 The "Rule of Nines" for estimating percentage involvement of body surface area (Wallace).

Depth. It has long been recognized that a superficial burn heals by local regeneration to leave little or no trace of its occurrence, whereas a deep burn heals by secondary intention with ulceration, the formation of granulation tissue, subsequent scar-formation, and contracture. Superficial burns involving only partial destruction of the epithelial layers of the skin heal spontaneously in 10–14 days, and in the absence of the grossest infection are little influenced in their course by the numerous therapeutic agents advocated since Hippocrates. Burns of slightly greater depth, leaving only sparse islets of surviving epithelial tissue constituting the remnants of hair follicles, sweat glands, or sebaceous glands, heal more slowly finally presenting varying degrees of epithelial instability discoloration, contracture, and loss of texture they may therefore require skin replacement. To the surgeon the essential feature is the preservation or otherwise of intact epithelium, so that the original classification of Dupuytren into six degrees of burning, and the wartime classification into three degrees, have been shortened into two more significant groups of partial and total epithelial loss. Table I shows the relationship of various classifications. Any attempt at clinical grading of depth of burning by rigid adherence to a system of classification by layers destroyed, inevitably tends to fail in burns involving the deeper *dermal layers*, where discrimination cannot be sharp. Variable depth of destruction *in the same area* of burning, the varying thickness of skin in different parts of the body (e.g. cheek and eyelid), and difficulties in the clinical diagnosis of depth by appearance *further* complicate attempts at precise classification in the individual case.

Table I. The Relationship Between Various Classifications of Burns by Depth

Dupuytren	War-time Classification	Clinical
I Erythema	First degree	Partial skin loss (or superficial) *Often subdivided into "superficial" and deep dermal.*
II Vesication (superficial epithelium destroyed)	superficial / Second degree / deep	
III Dermis involved		
IV Fat involved	Third degree	Total skin loss (or deep)
V Muscle involved		
VI Bone involved		

the thickness of the keratinized layers of the skin in the zone burned. Poor circulation in the involved skin may increase the liability of damage by failure to conduct away the heat applied (e.g. the hotwater bottle burn in the unconscious patient). These burns are usually superficial owing to prompt withdrawal, unless this is prevented by entanglement in machinery or by unconsciousness. The deepest and most destructive burns occur in epileptics, or in elderly people subject to attacks of unconsciousness from cardiovascular disease.

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Chemical, Electrical, and Radiation Burns. The distinctive features of these injuries will be considered later.

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The extent, depth, and site of the burn determine the severity of the injury in respect of risk to life, danger of loss of function, and duration of treatment.

Extent. Estimation of the burn in relation to the area of body surface involved provides within limitations a basis for initial assessment both of the severity of the systemic disturbance likely to occur and of the extent of constitutional treatment likely to be required for its mitigation. The extent, expressed as a percentage of total body area, may be calculated from Berkow's tables. Wallace (1951) has devised a simplified pictorial version by expressing the various zones of the body in terms of 9 per cent or multiples of

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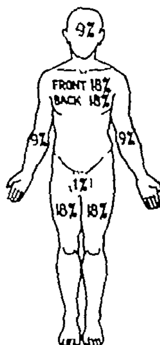


Fig. 110. The "Rule of Nines" for estimating percentage involvement of body surface area (Wallace)

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TABLE I. THE RELATIONSHIP BETWEEN VARIOUS CLASSIFICATIONS OF BURNS BY DEPTH

Dupuytren	War-time Classification	Clinical
I Erythema	First degree	Partial skin loss (or superficial) *Often subdivided into "superficial" and "deep dermal.*
II Vesication (superficial epithelium destroyed)	Second degree: superficial	
III Dermis involved	Second degree: deep	
IV Fat involved	Third degree	Total skin loss (or deep)
V Muscle involved		
VI Bone involved		

Site. MacIndoe (1940) has drawn attention to the importance of site in relation to subsequent functional disability. It is evident, for example, that contraction arising from a small burn on the palmar surface of the hand may give rise to a crippling deformity quite disproportionate to the functional impairment which would be caused by a burn of the trunk of equivalent size and depth. The areas of functional importance are the face, hands, joint flexures, feet, perineum, and external genitalia. Losses of skin in these situations require particular attention in respect of early skin replacement, and often demand subsequent specialized treatment.

LOCAL PATHOLOGY

Burns of the most minor degree are evidenced only by an erythema appearing after a period of seconds or minutes in the case of a thermal burn, hours (actinic burn) and days or weeks (ionizing irradiation). There is but little fluid leakage from the dilated capillary bed, with the formation of microscopic intra-epidermal collections of fluid at the most. Slight branny desquamation may occur but resolution takes place without scarring within a few days.

Burns affecting the deeper layers of the epidermis produce varying degrees of disruption, large blisters separating the damaged or coagulated layers. The damage to the capillary bed gives rise to (*a*) dilatation with slowing of blood flow and reduction of the normal hydrostatic pressure gradient, and (*b*) abnormal permeability to protein, with selective differentiation in favour of leakage of the smaller albumen molecule. *The result of these factors is the leakage into the tissue spaces of fluid of similar electrolyte constitution and two-thirds of the protein concentration of blood plasma, and the normal hydrostatic and osmotic pressure relationships of the capillary are deranged.* On the surface this fluid collects in vesicles as it separates the epithelial layers, and as œdema fluid in the surrounding subcutaneous zone, where it may accumulate in considerable quantities. The total protein concentration of the vesicle fluid is less than that of the circulating plasma, the highest concentration being found within the first few days after injury and showing a gradual decrease after the first 5 days; initially higher than that of plasma, the albumen globulin ratio after 36 hours shows a return of the ratio to the range of normal plasma (Moore *et al.* 1948). The ease with which the subcutaneous tissues allow physical expansion exert a minor influence on the rate of œdema formation; lax tissues, such as eyelids or scrotum, do not resist rapid distension, as compared to the more rigid and inelastic covering of the limbs. It is doubtful, however, whether the rising tissue pressure in the less elastic areas does more than slightly delay the rate of œdema-formation, the extent of leakage being proportional to the area of damage to the capillary bed whatever the zone burned, the exuded fluid merely percolating through the tissue spaces along the line of least resistance to occupy a wider area. After a few hours the fluid in vesicles and bullæ becomes coagulated with a fine network of fibrin strands. Healing takes place initially by migration and surface spreading of the residual epithelium of the skin appendages or inter-papillary processes, the thickness of the epidermis being built up later by mitosis.

In the case of deep burns the entire thickness of the epidermis is destroyed, and the dead tissue remains as an adherent slough. This slough varies in appearance according to the manner of burning; flame burns tend to produce a slough which is brownish or black, and may present a curious transparent appearance through which may be seen

coagulated fat and thrombosed blood vessels—"pork-crackling" slough (Fig. 111) steam burns tend to produce a white or marbled slough flash burns may give rise to such intense local heat that vaporization to the dermal fluid occurs, the entire skin being blown off by the resulting steam pressure and immediately coagulated (Fig. 112) The slough is normally depressed slightly below the surface of the surrounding inflamed and oedematous skin, which sometimes shows minute radiating folds as it is drawn inwards towards the slough owing to the slight contraction which takes place on coagulation. In the ensuing weeks, gradual separation of the skin sequestrum takes place as the underlying surface becomes reorganized into granulation tissue. A leucocytic exudate forms

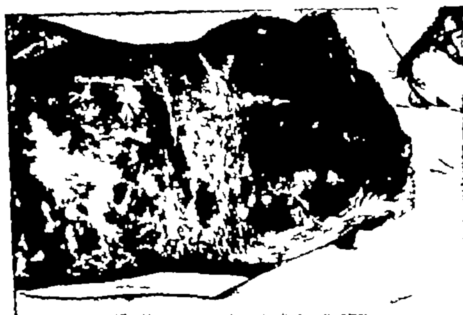


FIG 111 Deep flame burn of trunk showing translucent slough traversed by thrombosed vessels.

between the granulations and the slough, usually infected by invading bacteria, giving rise to abscess formation which may aid separation. The time taken for spontaneous separation varies with the depth of the slough where the line of separation is through the subcutaneous fat, separation may be complete in 4 weeks in more superficial burns where the deeper fibrous layers of the dermis anchor the slough to the subcutaneous plane, spontaneous separation may be delayed several weeks longer Separation occurs more quickly on the face than elsewhere. Loss of the slough leaves a granulating zone which can only heal by marginal growth of epithelium, assisted by the contraction which ensues from increasing fibrosis of the granulating base. Healing tends to be delayed by infection and the resultant excessive growth of pale granulation tissue and by the adverse affect of the proliferating fibrous tissue on the local blood supply The exposure of large areas of bone precludes healing. Fantastic degrees of contracture can occur where extensive areas are left to heal by natural processes the capacity of a large raw area to heal is largely dependent upon whether its situation allows sufficient contraction to occur

SYSTEMIC PATHOLOGY

The leakage of fluid from damaged vessels in the vicinity of an extensive burn leads to profound circulatory disturbances. The loss of fluid from the circulating blood volume is maximal in the first 8–12 hours after injury and extends over a period of 36–48 hours, by which time the œdema has attained its greatest volume. There is thus an expansion of the extracellular fluid volume which is roughly proportional to the extent of surface area burned, but this tends to reach a maximum value of 10 per cent of the body weight, that is 50 per cent above the normal, when the burn is sufficiently extensive



FIG. 112. Flash burn. This slough was one of four similar casts found dangling from the wrists of two firemen involved in an explosion of acetylene gas. Note how the plane of separation has detached the nails.

to involve 30 per cent or more of the body area. More extensive burns do not necessarily increase the volume of the extracellular fluid further but if greater expansion does occur either as a result of the injury or over-zealous fluid therapy there is grave risk to life.

In addition to this sequestration of extracellular fluid in the region of the burn, fluid loss takes place from the surface of the wound. The quantity of this exudate is variable. It is evident that in deep charred burns, losses from the dense surface coagulum will be negligible even in the case of superficial burns, external fluid loss can be diminished if a dry coagulum can be induced to form at an early stage. Estimations by Moore *et al* (1947) showed average surface losses of the order of 50 ml. for each 1 per cent of surface area burned during the first 48 hours such loss is very much less than may occur later during the granulating slough-separation phase

The magnitude of the possible fluid shift caused by localization of fluid in the vicinity of the burn may be appreciated by consideration of a hypothetical 50 per cent body surface burn in a 70 kgm. man, with a predicted expansion of extracellular fluid to 50 per

cent above normal. Commencing with a normal plasma volume of 3 litres and interstitial fluid of 11 litres (14 litres of extracellular fluid), an expansion of his extracellular space by 7 litres (10 per cent of his body weight) to 21 litres might occur over a space of 48 hours, assuming that such a degree of expansion can be met by withdrawal of fluid from cells or appropriate fluid intake.

First Phase. Capillary leakage. This relentless outgoing tide into the damaged area leads to an initial relative increase of the retained constituents of the circulating blood volume. Hæmoglobin and hæmatocrit readings show progressive hæmoconcentration and the plasma protein concentration is at this stage higher than normal. The viscosity of the circulating blood stream is accordingly raised, and the hæmoglobin value may rise to 140 per cent, or even 160 per cent in a child unless the plasma volume can be maintained by mobilization of fluid from undamaged tissue or by therapeutic administration, progressive oligæmia develops The natural resources of the body are brought into play to husband the dwindling blood volume and maintain the circulation in the face of increasing viscosity and diminished cardiac output. Reflex vaso-constriction maintains for a time the central blood pressure, but ultimately at the expense of the splanchnic and renal circulation in favour of maintenance of cerebral flow There is renal conservation of sodium, and maximal tubular reabsorption is promoted by the adreno-cortical response to stress. Urinary excretion falls to the obligatory minimum, probably as a result of excretion of anti-diuretic hormone as a reaction to increased plasma osmolarity (Verney 1947) Should the systolic blood-pressure fall below 90 mm. renal filtration may virtually cease, and the normal selective electrolyte-regulating mechanisms of the kidney fall into abeyance disturbances in the acid/base balance of the blood may occur and in the absence of persistent vomiting the tendency is towards acidæmia. Fluid is drawn into the vascular compartment from the undamaged tissue space, owing to the increased osmolarity of the bloodstream, and the plasma volume and blood pressure may be maintained for a time until this source is exhausted.

The rapid and massive expansion of the extracellular space leads to a fall in the concentration of the contained sodium ions and in the absence of sodium administration this change will take place whether the fluid deficit is made up by abstraction of fluid from the body cells or by the intake of water even if mitigated by the mobilization of sodium from reserves in the bones. If the low sodium concentration is made up with intravenous saline, a massive positive sodium balance naturally accrues from the sequestration of sodium in the wound œdema, and therefore occult at this stage It is therefore usual to find a falling plasma sodium concentration in face of a positive general sodium balance.

The patient thus suffers a progressive loss of water from the undamaged interstitial space owing to the continued depletion of the vascular space arising from immobilization of fluid in the burned area. If the compensatory processes break down from the excessive demands placed upon them, the progressive oligæmia finally gives rise to peripheral circulatory failure, and the body cells, already disturbed by water and electrolyte shifts, now suffer anoxia the normal "steady state" in which the body fluids and their constituents are so subtly balanced is disorganized, and circumstances thus arise which are no longer compatible to life.

Second Phase. Assuming that the patient has by mobilization of his reserves and by adequate therapy survived the disturbances created in the first phase, he now passes into

the second phase, in which the ebbing tide of fluid now turns, a change which may occur with dramatic suddenness, as the œdema fluid is reabsorbed into the vascular compartment. The damaged capillaries have recovered their normal level of permeability to protein, or have become thrombosed. The electrolytes are reabsorbed directly into the bloodstream, and the protein constituents are taken up by the lymphatic channels. The situation at the onset of this phase in an extensive burn may be that 7 litres of fluid, containing perhaps 1,000 m. eq of sodium and 280 gm. of protein, has to be removed and reaccommodated, either by redistribution elsewhere in the body by excretion, by losses from the wound, by perspiration, or by vaporization in the lungs The normal consequence if recovery is to ensue, is a sodium diuresis occurring 2–5 days after injury provided that the kidneys, the efficiency of which may have been reduced by previous disease, by anoxia or other factors in the acute phase, can excrete the large quantity of fluid involved. If renal excretion fails, with persistent oliguria or anuria, the surplus fluid tends to be distributed elsewhere, and there is a consequent liability to pulmonary œdema or cardiac embarrassment this danger is particularly increased by failure to recognize the termination of the leakage phase and by the continued administration of large quantities of saline. Whilst there is no question that the local accumulation of extracellular fluid is inevitable, and takes place whether steps are taken to maintain the plasma volume or not, it is evident that over-expansion of the extracellular space can be produced by over-estimation of the fluid requirements of the patient, unless urinary excretion of the excess fluid is achieved. If the lungs have themselves been damaged by the burn, the fluid loss in the lung may be out of all proportion to that of the external surface area burned, and a situation arise which may be quite uncontrollable.

Other Metabolic Disturbances

Nitrogen. In the first 48 hours after burning there is commonly a positive nitrogen balance, resulting mainly from plasma therapy but if the renal function is poor as is often the case nitrogen loss in the urine may be low because the circulating plasma is inadequately cleared (mainly of urea and ammonium) Whether due to plasma administration or failure of excretion a positive balance at this stage bears no relationship to tissue anabolism. After 48 hours the patient passes into a stage of negative nitrogen balance which may become profound in extensive burns, and lasts for 2–3 weeks or longer until the commencement of the healing phase. The nitrogen loss occurs in the exudate (this may be 25–30 per cent of the total) also in the urine, and the total may amount to 30–50 gm. a day It is usually impossible even with a forced dietetic intake, to maintain a severely burned patient in positive balance during this period. Urinary excretion of nitrogen tends to be maximal as the burned skin sloughs, and losses are increased by suppuration. During the healing phase the urinary nitrogen gradually becomes proportional to the intake, and it is eventually possible to maintain a positive balance with an intake of the order of 20 gm. daily Nitrogen balance and healing are closely related losses can be minimized by preventing suppuration, and by early slough-excision and grafting, curtailing the granulating phase. As a corollary failure to maintain an adequate nitrogen intake leads to prolonged convalescence, failure of grafts to take, and the dangers of long-continued granulation and sepsis

Potassium. There is a loss of potassium during the first 2–4 days after burning, but positive balance is rapidly attained when normal intake (over 50 milli-equivalents daily)

is established. As potassium is mainly excreted in the urine potassium retention is readily produced by oliguria and anuria this renders any attempt to replace supposed extra-renal losses by the administration of potassium potentially dangerous, unless preceded by measurement of the plasma level Although potassium is released on cell death when sodium enters the cells, the amount of extracellular potassium produced by such a process has been shown to be of too small an order to affect the patient as a whole even in extensive burns (Moore *et al* 1948)

Fat. Loss of fat is a constant and obvious accompaniment of the illness following acute burns. The normal rate of fat oxidation is about 75 gm. daily after burning the fat loss may reach 600 gm daily releasing 5 400 calories in the process. The mechanism which leads to such extensive fat catabolism is unknown. The restoration of fat may not reach its original level until the final stages of healing or later

Red Cell Damage and Anæmia

Primary Anæmia

The destruction of extensive areas of such a vascular tissue as the skin leads to the immediate loss of blood cells within the sequestrated area. Whilst this alone might be expected to produce a significant reduction in red-cell volume after massive deep burns, it is not the only factor this is evidenced by the not infrequent occurrence, during the first few hours after burning, of hæmoglobinæmia and bilirubinæmia, showing that red cell lysis has occurred in the circulating blood-stream outside the necrosed and thrombosed area. Occasionally frank hæmaturia may occur or hæmatenesis, indicating grave damage and carrying a poor prognosis. The ominous portent of profuse hæmoglobinæmia has been noted by many writers, and Harkins (1941) observed severe hæmoglobin staining of many organs at post mortem in a case dying 60 hours after burning. Moore and Cope (1945) have shown that the loss of red cells may be as high as 200 ml daily for the first 4 days after burning. It would appear that either the red cells are in some way damaged by heat at the site of burning, so that their life span is reduced, or that some hæmolytic agent is released leading to general red cell destruction. The influence of "sludging" of blood in this connection (Dragstedt *et al*., 1950) with alteration in the surface properties of the red cells, their agglutination into clumps, and associated generalized vascular changes, is not yet established in the human patient experimental work with animals suggests that there are three ways in which red cells might be lost to the circulation (*a*) cells trapped in agglutinated masses, (*b*) cells lost through the damaged vessel walls, and (*c*) phagocytosis of agglutinated cells

Secondary Anæmia

Severe anæmia is a constant accompaniment of deep burns in the period which follows the hæmodilution phase. It is greater than can be accounted for by primary blood destruction or by hæmodilution from therapy and has been shown by Braithwaite and Moore (1948) to be roughly proportional to the area of granulation tissue present. The onset of the anæmia is coincident with the period of negative nitrogen balance, but if healing is delayed may continue after a positive nitrogen balance is achieved. It is resistant to therapy with iron, hæmatinic factors, or Vitamin B and requires transfusions which often have to be repeated until the raw surfaces are covered. While blood losses from repeated operations and changes of dressings may be severe aggravating factors, it

would seem that there is in addition a depression of hæmoglobin synthesis. The relationship between this synthesis and an adequate intake of protein is well known, and it may be that the excessive demands of the body for protein may render the supply of essential globulin inadequate for hæmoglobin formation. Anæmia tends to be most marked in the infected case. Failure to correct the anæmia with transfusions leads to the development of a vicious circle when the hæmoglobin level is low (below about 60 per cent) healing is delayed, with suppression of active epithelial spread from grafts

Infection

The burned surface is usually sterile at first as a result of the heat applied, unless the circumstances of the accident lead to immediate infection. Subsequent bacterial contamination occurs from the patient's own skin or orifices, from unsterile dressings, or from the well known sources of cross-infection. The organisms commonly cultured from the burn are Staphylococcus aureus, α and β hæmolytic Streptococcus, Ps. pyocyaneus, B. Proteus, B. Coli, and the diphtheroids. Nearly all burns are found to be contaminated by organisms in the course of treatment. The extent to which this adversely affects the progress of the patient depends on (*a*) whether actual invasion of the living underlying tissue occurs, with the likelihood of local suppuration, constitutional disturbances, or even frank pyæmia, and (*b*) the influence of the organism on the successful take of grafts. It is uncommon under proper management for dangerous bacterial invasion to occur in superficial burns, but infection delays healing, and may be responsible for conversion of a superficial burn in the "borderline" zone into a deep one. In deep burns, in which the adherent sloughs may form closed infected wounds with underlying loculated abscesses, severe general symptoms of invasion are less uncommon. A dry coagulum with sterile surface may harbour an underlying heavily infected zone. Staphylococcus aureus may cause graft failure by the mechanical elevation of graft from base by pus the hæmolytic streptococcus may exert a lethal effect on grafted skin, possibly owing to fibrinolytic activity which prevents cohesion Ps. pyocyanus not only inhibits epithelial spread but actively digests living epithelium. Both the local bacterial activities and the constitutional signs of infection tend to be aggravated by local moist conditions and minimized by dryness and exposure The extreme facility with which the burned surface can become contaminated demands the most stringent precautions against all possible sources of cross-infection in dressing technique

Tetanus is a rare complication, and the incidence in this country is sufficiently negligible as hardly to warrant the routine administration of prophylactic antiserum In special circumstances, however when deep burns have been sustained in conditions liable to produce contamination with this organism, a prophylactic dose is advisable.

Toxæmia

The possible role of a specific toxin arising from the damaged tissue as a cause of illness or death has never been clearly settled. "Acute toxæmia" has often been evoked as a cause of death in the first few days, after it was considered that the circulatory disturbances had been brought under control. Degeneration and necrosis of liver cells, nephron damage in the kidney occurring in burns sometimes of comparatively limited extent and particularly in children, have been attributed to the action of a hypothetical toxin. Most of the post-mortem changes described can be accounted for by the effects of

local tissue anoxia. Unrecognized pulmonary damage may account for many deaths from comparatively limited burns of the face and neck. Toxic effects from absorption of tannic acid when this treatment was in vogue led to further confusion. Emphasis has now shifted again to the effects of the massive fluid and electrolyte disturbances which follow severe burning, and it seems probable that most of the deaths in the earlier stages can be attributed to damage of essential organs from tissue anoxia, due to failure to maintain an adequate circulation through them. In the case of deaths occurring later in the granulating slough-separation phase, it is difficult to assess the relative significance of the numerous adverse factors, including tissue autolysis and bacterial invasion, occurring in so large a wound

Alterations in the mental state during the first few days, which appear in the most striking form in children, are less often encountered today than formerly and have been attributed to "toxæmia." The syndrome often commences with vomiting, frequently persistent. Initial apathy gives place to drowsiness and irritability Twitching movements of the limbs and face occur during sleep, and coma or death may supervene. In adults, anxiety disorientation, and delirium may precede the onset of coma. These symptoms might be accounted for by over-hydration of the cerebral cells, the entry of water into the cells occurring from extracellular hypotonicity in a patient who has been allowed to drift into a state of water-intoxication during the phase of extracellular space expansion and sodium deficiency certainly the symptoms arise after massive shifts of body fluid and electrolytes are known to have taken place. The condition has also been attributed to the effects of toxic absorption of tannates on the liver (Wells, 1942), but it is still seen in cases untreated by tannic acid coagulation.

Summary

The constitutional changes discussed above can conveniently be summarized as follows

Phase 1 First 2–3 days. Expansion of extracellular space.

(1) Vascular leakage and development of wound œdema.

(2) Heavy positive sodium balance (assuming adequate therapy) due to obligatory isolation in œdema fluid and renal conservation.

(3) Transient positive nitrogen balance during plasma therapy possibly increased by oliguria.

(4) Transient potassium loss (may continue to third or fourth day)

(5) Early rise in 17 keto-steroid excretion Secretion of antidiuretic hormones with increasing plasma viscosity

(6) Loss of fluid from burned surface.

(7) Primary anæmia from blood destruction and possibly from "sludging."

(8) Possible development of nephron lesions from oligæmic conditions.

(9) Possible death in oligæmia if blood volume not maintained.

Phase 2. Succeeding fortnight to four weeks.

(1) Reabsorption of wound œdema.

(2) Sodium diuresis (third or fourth day but may be delayed to sixth) In event of renal damage, redistribution of excess fluid—pulmonary œdema and cardiac failure.

(3) Negative nitrogen balance. Renal excretion perhaps 30–45 gm. daily Duration 2–4 weeks, with heavy loss of both lean tissue and fat.

(4) Positive potassium balance readily attained.

(5) Sloughing, granulation, and infection of deep burns if provision of skin cover is delayed.

(6) Intractable secondary anæmia.

Phase 3. Convalescence Shift of metabolic balance to anabolism.

(1) Nitrogen balance proportional to intake. Lean tissue loss replenished.

(2) Epithelial proliferation at wound margins grafts spread.

(3) Hæmoglobin level maintained without transfusions.

(4) Reduction of wound loss of protein and electrolyte as surface is covered.

(5) These changes dependent on skin cover prevention of infection maintenance of caloric, protein, and vitamin intake

Complication of Burns

Intestinal Lesions. The occurrence of ulceration of the intestinal tract (Curling's ulcer) is a well known complication of deep burns. Harkins (1942) analysed various reported series and arrived at an average incidence of 3 8 per cent in necropsy cases. Such cases presumably represent burns of the most severe type, and the incidence in hospital practice is undoubtedly considerably lower The most common situations are firstly the duodenum and secondly the stomach more rarely the ulcer is found elsewhere in the intestinal tract. There is sometimes more than one ulcer The ulceration occurs at varying periods during the first 2 months or even longer after burning The progress of the lesion is rapid, and there is little time for the reparative processes of fibrosis hence penetration is rapid, and the ulcer may first declare itself by hæmatemesis from erosion of a large vessel or by perforation. The condition seems to be associated with granulation and suppuration of the raw surfaces, and may occur at any age.

Intestinal ileus is a rather uncommon complication in the early weeks following acute burns. Its onset is unpredictable and, in the absence of potassium deficiency its cause unknown. There may be a generalized paralytic ileus, or the paralysis may be limited to the duodenum, without demonstrable local lesion. An intractable diarrhœa is another complication occasionally seen it tends to persist until skin cover has been provided, and is usually associated with secondary anæmia and a failure to improve in weight, with a poor general condition.

Respiratory Tract Lesions. Immediate damage to the air-passages may occur in burns of the face and neck, with injury to the mucous membrane of mouth and tongue, laryngeal œdema, and an acute tracheo-bronchitis. Noxious gases inhaled when burns are sustained in confined spaces may also produce primary pulmonary damage. The inhalation of hot steam is particularly liable to cause a respiratory burn. If the damage extends to the alveoli pulmonary œdema ensues a vast area of capillary bed is exposed to thermal trauma, and the resultant out-pouring of fluid may cause the patient to drown in his own secretions. A vicious circle is set up if stagnation in the pulmonary circulation leads to cardiac failure. Therapeutic administration of intravenous fluid is liable to aggravate the water-logging of the lungs, and as the blood volume cannot be maintained, these burns are usually lethal

Broncho-pneumonia is a common terminal event during the stage of slough-separation, in a patient whose resistance is lowered by anæmia, nitrogen loss and suppurative processes in a large wound.

Renal Lesions. Renal damage is probably attributable mainly to ischæmia, and is uncommon unless there has been failure to control the initial oligæmia. Van Slyke and his colleagues (1944) have correlated the effects of hypotension with studies of renal clearance and histology they have shown that the immediate effect of hypotension is a fall in the renal blood-flow and filtration rate, due to a shutting-off of some nephrons, leaving others still functional. The result of this process, if prolonged, is a patchy ischæmic necrosis. In human cases evidence of tubular damage may be found 3–5 days after burning and a little later evidence of repair may be seen. The zones of localized damage show a random distribution throughout the tubule the common incidence of proteinuria in these cases suggest that some glomerular damage must have occurred even when they appear normal. The accompanying clinical features have been summarized by Muirhead and Hill (1948) into three phases. Phase 1—lasting 1–4 hours, presents the symptoms of hypotension and circulatory failure there is a purely functional depression of urinary activity with temporary oliguria and slight elevation of blood urea concentration. At this stage the condition responds to measures which replenish the blood volume but otherwise passes into Phase 2, with acute renal failure and accompanying structural changes There is now anuria or oliguria such urine as is passed is of low specific gravity (1005–1010) owing to failure of tubular concentration. Although the obligatory minimum urinary secretion of a normal kidney is in the region of 600 ml. daily such an amount may prove inadequate in a kidney unable to concentrate, so that uræmia, with mental confusion, nausea, and vomiting supervene, and the blood urea may reach 500 mgm per cent in a week. The urine shows the presence of protein and granular (frequently pigmented) casts, the serum potassium is elevated, and acidosis to some degree is usual. If the patient survives and repair ensues (Phase 3), the urine volume gradually increases, a process that may occupy up to 3 weeks. The diuresis may reach 10 litres daily with a specific gravity fairly constant at 1010 This diuresis may wash away Na and Cl ions, but in burns which have received full intravenous therapy earlier a deficiency is unlikely to occur The concentrating power gradually increases but may remain subnormal for months or years where the damage has been severe.

Osseous Lesions. Owens (1949) has drawn attention to the occurrence of decalcification of bones in burns, and reports a case of pathological fracture of the femur There is a diffuse and patchy osteoporosis of the bones of the limbs, which Owens attributes to hyperæmia rather than to disuse. The condition has only been seen in severe burns of the "chronic" type.

Hyperpyrexia. This complication occurring as a rule in a patient already seriously ill is frequently lethal. The relative significance of a general disturbance of heat regulation on the one hand or fulminant bacterial invasion on the other is not known. Aggravating factors are (*a*) loss of extensive areas of skin with consequent reduction in the ability to lose heat by sweat evaporation and capillary dilatation, and (*b*) the presence of voluminous dressings which further preclude heat loss, both from their insulating effect and from their contained moisture, which raises the local humidity and prevents sweat evaporation when undamaged skin is covered.

Late Complications

Scar Hypertrophy Proliferation of fibrous tissue with the production of raised florid, shiny irritable, and sometimes painful scars is an unfortunate complication of full

thickness burns, and sometimes of deep dermal burns, leading to considerable difficulty in treatment. The proliferation commences during the early weeks after healing has been obtained, and is directly related to the thickness of residual dermis between the epithelium and the underlying base. Several factors influence this change (*a*) individual susceptibility of the patient, (*b*) age group—the condition is commonest in children and young adults, (*c*) the adequacy of skin replacement intermittent tension is an aggravating factor and tight scars across joint flexures usually show the most prominent hypertrophy the scarring also delineates the gaps between grafts applied as isolated patches or strips, and (*d*) the mode of burning hypertrophy is particularly common after chemical burns and uncommon following electrical burns. The susceptibility to scar hypertrophy is associated with the liability to contraction of the grafted areas.

Contractures. These occur both in the course of the natural processes or repair in an untreated burn, or to a lesser degree in grafted burns from contraction of the base of the grafted area. As a result severe loss of range of movement may occur in joints, and appalling distortions may result in the mobile portions of the face. Whereas contractions across joints may persist for many months or years in the case of children, and full movement still be regained on addition of the required area of skin, adults tolerate such prolonged splintage badly associated shortening of joint ligaments and capsule takes place and if the contracture is allowed to persist full movement may never be regained.

Carcinoma. Carcinoma arising in burn scars (Marjolin's Ulcer) is not particularly rare, and is usually seen in old untreated burns in which the initial healing was long delayed, and the final skin cover thin, scarred, inelastic, and unstable.

Diagnosis

The depth of the burn determines the nature of the primary therapy the necessity for grafting, the duration of invalidism, and the final prognosis. It is usually easy from the appearance of the burn to diagnose the extremes of damage. Superficial burns merely cause erythema or the production of unruptured blisters rupture of these blisters discloses a highly sensitive surface which may show evidence of return of circulation on release of light pressure Deep burns are readily recognized when the skin is obviously charred or coagulated, especially when thrombosed vessels are visible in the coagulum. Between these two extremes it may be difficult or impossible to determine whether the whole thickness of the skin has or has not been lost in the first few days after injury Some assistance in assessment may be given by the history of the injury and the knowledge of the differing structure of the skin in different parts of the body The appearance of exposed dermis, which may be white or flushed, is particularly deceptive in the first few days. Points in favour of the burn being deep are the following (*a*) The dermis presents as a white shiny surface, with punctuate scattered red areas which cannot be dispersed by pressure and are seen on close inspection to be small extravasations of blood. (*b*) No evidence of colour return appears on stroking the burned zone with an instrument. (*c*) There is no sensation to pinprick over the area this sign may be equivocal, because although the presence of sensation is a good indication that the burn is superficial, absence of sensation may be produced by dermal oedema in the absence of complete epithelial loss (*d*) The burned area is slightly depressed below the surrounding skin which shows minute tension creases radiating from the hyperaemic margin. Even with considerable experience, however it is frequently impossible to judge the depth of a burn

by its initial appearance, and this becomes particularly true after burns have been treated by any form of coagulation method.

Prognosis

In order to provide a yardstick against which the relative efficiency of various methods of treatment may be measured and improvements assessed, it is of considerable importance that some means of analysing the death-rate from burns be devised. Unfortunately the problem is a complex one, with many variable factors the general incidence of burns, fatal and non-fatal, is not known, multiple advances in therapy have meant the employment of several improved methods synchronously and the crude mortality statistics of series of cases as frequently published bristle with possible fallacies if used for purposes of comparison.

Colebrook (1949) reported a mortality rate of 4 8 per cent in 1 000 cases admitted to the Birmingham Accident Hospital during 1945–48. This figure represents the crude death rate which can be expected with highly efficient treatment of burns in patients in whom the age-distribution, social levels, and occupation are probably representative of the "average" for the country

Initial assessment of the chances of survival in the individual case must take into consideration all the relevant factors, of which the most important are age, general physical condition at the time of the accident, associated injuries, any delay occurring before commencement of treatment, extent and depth of burning, and that intangible quality the will to live.

Bull and Squire (1949) have emphasized the importance of standardizing the two factors of age of patient and severity of burn in any analysis of burn mortality The mortality for a series of 1,570 burns treated at the Queen Victoria Hospital, East Grinstead, during 1940–53 is shown graphically in Table II with the extent plotted against the age. The rising mortality with increasing age for a given percentage area of burning is clearly apparent. A similar result was found by Bull and Squire, who formulated their findings into a table showing the chances of survival of patients of different ages with a given extent of burn.

In general it may be said that a burn involving less than 10 per cent of the body area is unlikely to endanger life except in the very aged. A burn of 30 per cent body area always produces constitutional disturbance which may be severe, is likely to carry a 50 per cent mortality risk in middle age, the risk rising with advancing years, and the course likely to be considerably influenced by treatment. Extensive burns involving more than 40 per cent of the body area involve grave risk to life at all ages.

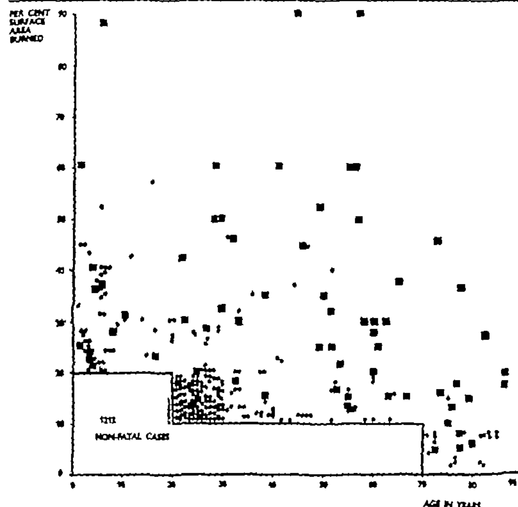
TREATMENT

The aims of treatment are to save life, to alleviate suffering, to shorten the period of invalidism, and to prevent or correct deformity This involves the control of metabolic disturbances as they arise, the local treatment of the raw areas by conservative or surgical measures, and the prevention of loss of morale which may result from pain, prolonged treatment with inadequate progress, or fear of deformity with its social and economic consequences.

Although it is convenient to consider the general and local aspects of treatment separately they are in practice closely inter-dependent. Constitutional disturbances may

delay healing and may themselves be maintained by the persistence of raw surfaces treatment must be directed to the correction of both local and general deficiencies if a vicious circle and the development of a "chronic" burn is to be avoided. Similarly it is a mistake to submit a patient with an extensive burn to time-consuming local dressings, anaesthesia, and even operative procedures, whilst he is in the precarious state of uncorrected circulatory disturbance.

TABLE II. RESULTS OF TREATMENT OF 1570 BURNS TREATED AT THE QUEEN VICTORIA HOSPITAL, EAST GRINSTEAD FROM 1940–1951, CHARTED AS SURVIVALS OR DEATHS IN RELATION TO AGE OF PATIENT AND EXTENT OF BURN. ■ = DEATH, O = SURVIVAL



General Treatment

Fluid Replacement. Treatment in the initial phase is concerned with the replacement of fluid lost from the circulation, and consideration has to be given to (*a*) the route of administration, (*b*) the amount of fluid required and the rate at which it should be given,

and (c) the type of fluid required. As the fluid loss commences at the time of burning, it is important that therapy should be started at the earliest possible moment: patients with severe burns should be admitted to hospital without delay.

Route of Administration

Patients with less than 10 per cent of the body surface burned do not require intravenous fluid, the estimated fluid loss being added to the normal oral intake. It is generally advisable to administer fluid intravenously with burns of over 15 per cent, and with burns of over 10 per cent in young children. Great care should be taken to avoid unnecessary trauma to veins: patent veins may become very precious if subsequent treatment has to be prolonged.

Amount of Fluid Required and Rate of Administration

It cannot be too strongly emphasized that whilst it is essential to formulate an initial plan of fluid administration, any rigid adherence to a system based on purely theoretical considerations is bound to prove unsatisfactory. The initial assessment of the likely requirements of the case must be modified to meet as far as possible the actual needs of the individual patient. It is therefore essential to control the rate and volume of administration by frequent reference to the general condition of the patient and his response to therapy.

Preliminary estimation of the total amount of fluid likely to be required is based on the fact that the fluid loss is likely to be proportional to the extent of the burn, and the weight of the patient. As the loss is greatest in the first 12 hours and is likely to persist for 48 hours, the rate of administration should be greater during the first day than the second. Cope and Moore adopted a basic figure of 150 ml. of fluid per 1 per cent of body surface burn in a 70 kg adult during the first 24 hours, half this quantity being given during the second 24 hours. It is most convenient to calculate the total probable requirement for the whole 48 hour period, to divide this figure into thirds, and to administer three equal quantities in the periods 0–8, 8–24 and 24–48 hours after the burn. Working on a basis of 220 ml. per 1 per cent of body surface burned in adults for the 48 hour period, Wallace (1954) has elaborated a table showing the requirements at different ages which works very well in practice (Table 3). This table assumes average weight for age (Table 4). The danger of extracellular space expansion above 50 per cent of the normal has already been discussed: in burns over 30 per cent of the body surface, therefore, the total fluid requirement is calculated on the basis of 10 per cent of the body-weight (1 kg. = 1 litre). This figure may have to be exceeded if the degree of oligæmia demands the administration of more fluid, but only with great caution. In estimating fluid requirements from body weight, it should be borne in mind that the volume of extracellular fluid is proportionately larger in infants, that men have a higher total water content per cent body weight than women, and that the total body water content tends to decrease with advancing age.

If delay occurs in commencement of treatment, the rate of administration must be correspondingly advanced.

The calculated total represents the fluid lost by sequestration in the vicinity of the burn: the patient must receive in addition sufficient fluid to cover his normal metabolic requirements (Table 5). This is given whenever possible in the form of repeated small

TABLE III. PLASMA AND ELECTROLYTE REQUIREMENTS AT DIFFERENT AGES (WALLACE)

Age (year)	Birth to [illegible]	[illegible]	[illegible]	[illegible]–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11 12	12–13	13–14	14–15	15–16	16–17	17–18	Adult
Electrolyte solution (ml.)	7	10	12	13	15	21	24	27	31	35	40	44	46	51	56	62	67	78	88	96	104	110
Plasma (ml.)	7	10	12	13	15	21	24	27	31	35	40	44	46	51	56	62	67	78	88	96	104	110

TABLE IV AVERAGE WEIGHT AT DIFFERENT AGES (WALLACE)

Age (year)	Birth to	[illegible]	–	[illegible]–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	Adult
Weight (kg.)	5	7	9	10	13	15	17	18	20	22	24	26	29	32	35	39	43	48	54	59	65	70

TABLE V FLUID INTAKE (AS GLUCOSE DRINKS OR WATER) REQUIRED TO COVER NORMAL METABOLIC REQUIREMENTS (WALLACE)

Age (year)	Birth to [illegible]	[illegible]	[illegible]	[illegible]–1	1 2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	Adult
Metabolic requirement (ml.)	700	1000	1150	1200	1300	1400	1400	1400	1500	1500	1900	1600	1600	1700	1700	1800	2000	2200	2400	2600	2800	3000

glucose drinks by mouth In the presence of vomiting it is given as isotonic dextrose-saline intravenously

Once the fluid requirements have been planned and administration commenced, a close watch is necessary on the condition and response of the patient this is particularly important in children with their more labile physiology The path between oligæmia on the one hand and overloading with fluid on the other may be narrow and in difficult cases hourly observation may be necessary The following observations aid control

(*a*) The general condition of the patient—blood pressure, pulse rate, signs of dehydration, distention or collapse of superficial veins, loss of fluid by vomiting, presence of cyanosis, etc.

(*b*) Urine output. Hourly estimation of the urine output is the observation of greatest single value as a measure of the adequacy of therapy An indwelling catheter is passed and hourly measurements made the hourly specimens are collected for measurements of specific gravity or any other investigations required. An hourly output of over 50 ml. per hour can be considered satisfactory in adults.

(*c*) Hæmoglobin percentage or hæmatocrit readings. These are repeated at 4-hourly or if necessary more frequent intervals as an indication of blood viscosity an increased reading showing that therapy is lagging behind fluid leakage and vice versa. Hæmoglobin estimation has the advantage over hæmatocrit readings in that repeated venepunctures, which may be very difficult in oligæmic children, are not required but errors may arise from any squeezing of tissue to extract blood, or because the state of the peripheral capillary field may not be representative of the main circulation. Both may be invalidated by red cell destruction in deep burns, a relative hæmoconcentration being masked by primary anæmia. Nevertheless serial estimations provide an additional check in conjunction with other findings.

(*d*) Other laboratory studies, including estimation of plasma sodium, protein, or potassium, A/G ratio, alkali reserve, and blood urea can give additional information if laboratory facilities are available to provide the prompt service required as they are usually not, emphasis is placed here on such clinical investigations as can readily be carried out by those immediately responsible for the care of the patient.

The Type of Fluid Required

On the basis of the pathological findings previously discussed, the nature of the fluid administered depends on the depth of the burn. Patients with superficial burns are given equal parts of plasma and isotonic saline. Dextran has proved an efficient plasma substitute in this context, and has one advantage over pooled plasma in the elimination of the risk of subsequent infective jaundice. Infants have a low renal capacity for excretion of sodium, and if the fluid requirement is large, reduction of the saline intake by substitution of isotonic glucose-saline may be advisable.

In deep burns, red cell destruction should be countered by whole blood transfusion, both to prevent initial tissue anoxia and to reduce the liability to subsequent anæmia. Blood is substituted for plasma according to the extent of the area of deep burning, and in very extensive deep burns it may be advisable to give the entire plasma requirement as whole blood. Blood has also been found of value in very extensive superficial burns, particularly when there has been delay in the commencement of treatment and the patient is suffering from an established oligæmia patients whose blood pressure remains

obstinately low in face of intensive plasma and electrolyte therapy sometimes respond very favourably to whole blood transfusion

Cessation of Intravenous Therapy Ideally intravenous administration should cease at the end of the 48 hour period of capillary leakage, and diuresis should follow The general condition of the patient determines whether intravenous therapy is discontinued early or late. The danger of continuing fluid therapy during the period in which the patient is endeavouring to eliminate his excess extracellular fluid is evident. Undue delay in the onset of diuresis, persistent oliguria, or anuria cause considerable anxiety at this phase. If renal damage has occurred, as evidenced by azotæmia, anuria, or persistent oliguria with failure to concentrate, steps must be taken to restrict the fluid and protein intake, whilst renal damage which is not irreversible undergoes the processes of repair Bull (1949) recommends restriction of the fluid intake to the amount lost by extra-renal channels (normally less than 1 litre daily), and provision of a diet consisting of glucose 400 gm. and fat 100 gm (peanut oil) emulsified with acacia in a litre of water and providing a caloric intake of 2,500 daily The mixture is administered by slow intragastric drip through a Ryle s tube. The important features are the reduction of fluid intake to the region of 600–800 ml daily and the omission of protein from the diet the oily component is not essential. It should be borne in mind that elderly patients with previously damaged kidneys of poor concentrating power may prior to burning, have required to pass a minimum urine volume considerably in excess of the normal for necessary excretion of waste products such patients may have needed to sustain a minimum obligatory urine output perhaps as great as 2 litres daily to avoid uræmia. Obviously prolonged restriction of fluid intake is dangerous to such patients.

Warmth. The fall in body temperature occurring in the initial collapsed state must be countered, but care should be taken not to overheat the patient. Local heat promotes pain in superficial burns, and general overheating may increase the degree of oligæmia. Increase in room temperature is thus preferable to the use of electric cradles or similar apparatus.

Sedation. Although the onset of pain after burning is often delayed, and even the severely burned patient may often exhibit a surprising lack of pain for the first hour or so, it is wise to administer a sedative immediately to allay restlessness and apprehension. The onset of pain, with the necessity to induce rest and sleep, and the reduction of oxygen requirements, demand particular attention to adequate sedation. Morphia or pethidine are the most useful drugs in the initial phases, but it is wise to substitute phenobarbitone, with soneryl or similar hypnotic at night, when possible. In children over 1 year of age, working from adult dosage values of Tinct. Opii ♏30 and Inj Morph. Sulph. gr ¼ the maximum dosage of these preparations can be calculated safely from Dilling's rule, modified to read

$$\frac{\text{adult dose} \times \text{age last birthday}}{20}$$

Diet. The requirements after a severe burn are large, and the diet should be of high caloric and protein value with supplementary vitamins and iron. Failure to ensure an adequate nutritional intake aggravates wasting, delays healing, lowers morale, and if life is preserved allows the transformation of the individual into that apathetic and querulous scrag of skin and bone—the "chronic burn." Even with adequate feeding it is often

impossible to prevent the serious fat loss which persists until healing is attained. The adult diet should provide a total caloric intake in the vicinity of 2,500–3 000 calories and contain not less than 150 gm. of protein daily The high caloric value of fat is useful in providing a high energy value in relation to bulk, and can form a third or more of the total intake. Practical difficulties in administering such a diet which should be commenced as soon as diuresis is established, arise from the following (*a*) lack of co-operation from the patient, owing to loss of appetite, and the discomfort and effort of eating (*b*) excessive bulk of a full high protein high caloric diet (*c*) lack of variety in diet and (*d*) shortage of nursing staff with limitation of the time which can be devoted to inducing the patient to take food by persuasion or actual spoon-feeding. For these reasons it is usually best to provide an ordinary light diet, containing two eggs daily and a reasonable portion of meat or fish, and to add to this supplementary feeds of fortified milk between meals. Three pints of milk should be given in this way daily with protein concentrate added in the proportion 1 ounce to 1 pint this can be varied by making up as ice-cream, various milk drinks or sweets, and glucose may be added to increase the caloric value. If this scheme for one reason or another fails, as is often the case, it is necessary as a temporary measure to resort to tube feeding, and this is in many ways the most satisfactory method of ensuring an adequate intake. An intranasal tube is passed and left *in situ* a measured volume of milk containing protein hydrolysate and glucose is fed by slow drip, the amount required depending on the food selected by the patient in his ordinary diet. It is important to resist the temptation to over feed in this way the drip should be stopped during the night to allow the upper digestive tract the normal period of rest.

Respiratory Complications. Upper respiratory tract obstruction from œdema may demand early tracheotomy Burns involving the lungs present an unsolved problem in treatment. There is little that can be done beyond the administration of oxygen to alleviate cyanosis and cardio-respiratory distress, and of antibiotics as a prophylaxis against secondary infection. In the case of patients suffering from a purulent bronchitis or incipient broncho-pneumonia with profuse muco-pus in the air passages, and who require anæsthesia if the raw surfaces are to be covered as a life-saving procedure, preliminary postural drainage and physiotherapy is beneficial, and the operation may be preceded or concluded by bronchoscopy and bronchial aspiration.

Secondary Anæmia. Frequent routine estimations of the hæmoglobin level are necessary after deep burns, and repeated transfusions given as indicated. As this matter is rather closely related to the patient s surgery transfusions are often conveniently arranged to commence with anæsthetic induction, and can then be regulated during and after the operation by the blood loss sustained.

Local Treatment

The aim of local treatment is to promote healing by spontaneous epithelialization or by grafting at the earliest possible moment, thereby minimizing the ultimate deformity and loss of function. Factors bearing on the achievement of this aim are (*a*) the prevention of infection (*b*) dispersal of œdema (*c*) limitation of surface wound losses (*d*) rest of the injured parts (*e*) early active movements to prevent joint stiffness and (*f*) the production of local physiological conditions favourable for epithelial growth and avoidance of applications which discourage such regeneration. The difficulty or impossibility of satisfying all these factors has resulted in the local treatment of burns being

a subject of controversy for a long period and is responsible for the variety of remedies which have been used.

In 1887 Copeland advocated the exposure of burns to the air to allow drying and surface coagulation the method gradually fell into disrepute owing to the occurrence of gross sepsis in deep and otherwise untreated burns. In 1925 Davidson introduced tannic acid, substituting an artificial coagulum for the natural crust of simple exposure the rapidity with which a thick, dry crust could be formed tended to prevent both the ingress of organisms and the loss of exudate, but serious disadvantages arose from pus formation beneath the dense coagulum over surfaces already contaminated, and from failure to cope adequately with the situation arising when slow separation of coagulated sloughs and concurrent infection occurred in deep burns. Evil results from coagulation of fingers and face, and the possibility of absorption of tannate with danger of liver damage, added further disadvantages.

The recognition that early replacement of skin was the prime essential in deep burns, together with the availability of chemotherapy gave impetus at the commencement of the war to methods designed to achieve early slough separation and the production of a surface suitable for grafting. During the war the usual principle was to encourage slough separation by repeated flushing with saline at the same time control infection with local or general chemotherapy Highly successful results were achieved by MacIndoe (1940) with the use of saline baths the provision of apparatus for automatic delivery of saline at controlled temperature and concentration enabled the patient to be immersed in the bath, dressings removed, physiotherapy conducted, and debridement carried out, prior to redressing with a tulle-gras base covered by absorbent dressings. This method is still undoubtedly the best in certain circumstances. An alternative method was the use of saline and hyperchlorite irrigations carried out through Bunyan-Stannard waterproof envelopes in which the burned limb or even trunk could be inserted. The advantage of these methods in providing free movements of joints, tendons, and muscles, and in allowing early grafting, are offset only by the difficulty of avoiding secondary infection of the raw surfaces. The use of occlusive pressure dressings was adopted by many the pressure was applied by firm crepe bandaging over voluminous dressings and if skilfully done was said to minimize œdema formation. The dressings were changed as infrequently as possible but had to be renewed before saturation of exudate through all layers to avoid cross-infection. There is some doubt whether this method produced any significant modification in the volume of œdema fluid formed, although by dispersal of the œdema over a wider zone it may have aided reabsorption. In deep burns this method has to be followed up with early surgical interference if infection is to be avoided in the phase of slough separation the danger of application of tight bandages by inexperienced persons, and the immobilization which results from the bulky dressings are disadvantageous.

In this country Wallace in 1951 advocated a return to the exposure technique, in the knowledge that light, dryness, and cooling are inhibitory to bacterial growth, that coagulation limits external wound fluid losses, and that the original difficulties of the method as used in the last century could be mitigated by the use of antibiotics, proper constitutional care, and judicious slough excision in deep burns.

An evaluation of the relative merits of different forms of treatment must take into account the fact that success with any particularly method is to a high degree dependent on the standard of nursing and surgical care and the attention paid to detail with good

management excellent results can be obtained with different methods, any of which may fail if the continuous detailed care and supervision necessary are lacking. The choice of method, be it by exposure or by some technique of dressings, is largely dictated by the nature of the case, treatment being suited to the particular needs of the individual patient. It should be realized that superficial burns will heal spontaneously within 14 days or at the most three weeks in the absence of severe infection or the application of substances inimical to epithelial growth any treatment, whether involving exposure or application of dressings, which fulfils these provisos will allow the natural process of healing within this time period, and the actual form of treatment adopted negligibly affects the final result. The real problems of selection of treatment and management therefore arise mainly in the case of deep burns. The majority of burns are treated today either by the application of occlusive dressings or by exposure, or a combination of these two

It is of some importance that the scheme of treatment adopted should not necessitate repeated anæsthetics for mere changes of dressing. It is not uncommon for patients in general hospitals to be submitted to half a dozen anæsthetics during the first 3 weeks after the burn before any reparative work is contemplated. This is not a good practice frequent anæsthetics increase the liability to pulmonary complications and interfere with the patient's feeding moreover as the more severe cases may require multiple staged operations in the course of future repair the lower the total number of general anæsthetics given the better from all points of view Therefore, if dressings are to be changed, means must be found of doing this as painlessly as possible apart from lowering the morale of the patient, pain usually signifies the infliction of further trauma on the regenerating tissues.

Treatment by Exposure. If the burns are clean and the patient is admitted within a few hours of injury no cleansing of the burned surface is necessary dirty burns are cleansed by gentle swabbing with 1 per cent Cetrimide Small unruptured blisters may be left to reabsorb during the next 4–5 days, but large blisters usually rupture if left and the dead overlying epithelium should be removed and trimmed back. This minimal interference with the burned area can usually be conducted with sedation only and is carried out after commencement of fluid therapy The unburned parts are covered and the burns left exposed. If large areas are involved it is advisable to cover the patient with a cradle to conserve body warmth, particularly in the early stages of circulatory disturbance. The room should be without draughts and ideally at a temperature of 70–75°F *It is* advisable to apply an initial "frosting" of penicillin powder to the raw area as a precaution against infection before the crust is formed, although this is not universal practice. The length of time the crust takes to form varies from 1–3 days The patient is positioned to keep pressure off the burned area, and maintain its exposure œdema formation in the extremities being reduced by elevation any cuffs or slings used for this purpose require careful application and frequent inspection lest pressure sores or worse damage occur in a swelling limb whose circulation is deranged. On the whole, retention apparatus of any kind is best avoided, but the use of a gallows splint in young children for the suspension of legs in perineal burns is useful. Cracks which occur in the crust at the sites of movement at joints should be dusted with powder to aid drying. Frequent small changes in position are necessary to aid comfort and avoid pressure troubles. Once *formed*, the crust remains dry odourless, and moderately flexible the burn is relatively painless. Burns several days old and already infected can be exposed after preliminary cleansing

and removal of any crusts overlying pus the change in general condition, with reduction of the previous pyrexia is sometimes remarkable.

In superficial burns, the crust separates and may gently be removed as its edges become raised within 14–16 days. If real doubt exists concerning the depth of the burn, it may be wise to wait 3 weeks before deciding upon surgical removal of residual adherent crusts, as separation may occur even after this period and still leave an acceptable epithelial surface. Deep burns should always be excised at or before the third week as far as their extent will allow burn excision is discussed later

The exposure method provides certain great advantages. Infection is minimized by dryness freedom of movement unimpeded by bulky dressings and the relative absence of pain, add to the general well-being of the patient. Local care of the burned surface is a trifling labour compared with the time and material expended in the treatment of extensive raw areas with absorptive dressings. There are however certain limitations and difficulties, which may be summarized as follows (*a*) The maintenance of a dry crust in circumferential burns of the trunk are difficult, sogginess occurring from pressure. This is not entirely overcome by frequent change of position or the use of a turning bed. (*b*) Without specially equipped wards it may prove difficult to maintain the temperature of the surrounding air and avoid chilling during the winter months, particularly if the patient is elderly Infra-red flood elements mounted on the ceiling help to overcome this difficulty (*c*) Some patients, particularly the old, cannot tolerate the prone position in dorsal burns. (*d*) Deep circumferential sloughs on limbs may endanger the circulation if allowed to become hard this may be overcome by slitting them longitudinally The method is unsuitable for burns of the hand. (*e*) Although exposure is effective in superficial burns of the face, it is less satisfactory in deep burns, owing to the formation of a rigid coagulum which may prevent movements of the lips, or closure of the eyelids long before ectropion develops from contracture. In spite of opinions to the contrary dry exposure of deep burns of the face is not advocated. (*f*) It is more difficult to estimate the depth of burning in doubtful cases in the presence of coagulation.

Treatment with Occlusive Dressings. The principle of this method is the prevention of cross-infection by the use of bulky dressings, which absorb exudate from the surface of the wound, thereby encouraging surface dryness the dressings become permeable to infection from without when saturated, and must therefore be changed before this occurs, but otherwise are changed as infrequently as possible. The burns receive preliminary cleansing as described above. As regards the material applied directly to the raw surfaces, it should be (*a*) non-adherent, so that it may be removed with minimal pain and trauma to the regenerated surface and (*b*) freely permeable, so that the exudate does not become entrapped and loculated beneath it If this occurs, the surface of the burn becomes soggy and infection with pus formation is almost certain to occur If the mesh is too wide the material tends to cut into the raw surface and become partially incorporated in the healing tissue If too fine, egress of exudate is prevented. The ideal material has yet to be found tulle gras is usually employed. Proprietary preparations are produced in rather small sheets, and if extensive burns are to be dressed it is best made up and sterilized in hospital where suitably large sheets can be prepared for convenient rapid application. Over this non-adherent base is applied a layer of gauze, followed by a copious surrounding packing of absorbent wool Dressings are best applied in the long axis of limbs rather than in encircling fashion, to allow for subsequent

swelling. Fixation of the dressings is maintained with crepe bandages applied firmly but not tightly additional security is obtained by judiciously applied strips of elastoplast or a few turns of plaster bandage. Many tailed bandages constructed from 6 in. crepe are convenient for securing dressings of the trunk. When extensive trunk burns are dressed, the dorsal portion of the dressing may be prefabricated in all layers to the correct size, and set out on a sterile towel upon which the patient is gently placed. The greatest possible care has to be taken to avoid secondary infection during the dressing burns should not be dressed in the open ward, but in a room especially equipped for the purpose, with adequate arrangements for the disposal of waste dressings, a suitable temperature, and facilities for a full sterile non-touch technique. Colebrook (1950) has emphasized the dangers of airborne infection and the advantages of forced ventilation of the dressing room with "clean" filtered air

Saline Baths. The provision of a saline bath in or adjoining the burns dressing-room is particularly valuable in the management of the following types of case (*a*) extensive burns after grafting at first and subsequent dressings (*b*) the neglected and suppurating extensive deep burn requiring a brief period of cleansing, general hygiene, and constitutional build-up before operation and (*c*) very extensive deep burns in which part but not all of the slough has been excised and grafted, during the period prior to further slough excision and grafting. The bath, which requires sterilization with carbolic swabbing between cases, is provided with apparatus in an adjoining room to supply constant flow of normal saline at a controlled temperature this can be delivered through a hose after preliminary filling of the bath. After removal of the outer dressings, the patient is immersed in the bath. The remaining dressings are gently removed as they are soaked off, together with any separating slough which may be detached piecemeal. Active movements can be carried out in the bath under the supervision of a physiotherapist. The patient is then lifted out of the bath and laid on a trolley previously covered with sterile towels, and fresh dressings are applied. Properly used, this system adds greatly to the general comfort and hygiene of the patient, aids function, and is a valuable method of immediate preparation for operation in the type of case under consideration. The process is somewhat time-consuming, and requires a staff of three, two of whom should be male in view of the heavy lifting involved.

Chemotherapy and Antibiotics

The advisability of the topical application of antibiotics or bactericidal chemicals has been a source of considerable controversy It has been stated on the one hand that the dangers of infection are such that a prophylactic barrier should be applied to the surface of the burn as a routine, and on the other that routine applications lead to the breeding of resistant organisms, variable absorption into the patient's blood-stream in subminimal or toxic dosage, and individual sensitivity to the substance applied.

In exposed burns topical applications are probably inessential, but reliance is placed on prophylactic systemic administration of penicillin during at least the initial stages. Jackson and his colleagues (1951) at the Birmingham Burns Unit have made a good case for the routine local application of penicillin cream (10 000 units per gm.), together with systemic aureomycin, in the prevention of streptococcus pyogenes infection of non-exposed burns. Swabs should be cultured from the raw surfaces at various points when

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the burn is first admitted and at subsequent dressings, and the *sensitivity of any colonizing organisms to the various antibiotics estimated.* Ideally the general or local therapy can be modified according to the findings and the appropriate antibiotic administered. In the presence of constitutional signs of severe infection it may be unwise to delay treatment until investigations are complete: in these circumstances achromycin is probably the most generally useful systemic antibiotic. *It is useless to apply local antibiotic creams for long periods to the surface of deep sloughing burns:* such treatment only produces maceration and fails to reach the infected zone which lies beneath



FIG. 113. Burn excision. (*a*) The forehead portion of this contact burn was excised and the wound margins advanced and sutured on the fourth day. (*b*) Result 18 months later.

the slough: whenever possible surgical revision should be undertaken before this troublesome state of affairs occurs. *Ps. Pyocyaneus responds favourably to topical treatment with polymixin E.* It is, however, an inhabitant of moist and macerated surfaces, the best prophylaxis being dryness: early slough excision further hinders its multiplication. Routine topical application of the sulphanilamide drugs is inadvisable.

The Surgical Preparation of Surfaces for Grafting. Localized burns of limited extent are well treated by immediate excision and grafting (Fig. 113). This applies mainly to contact, chemical, or electrical burns of functional areas. In patients with extensive burns, the sloughs should be excised whenever possible before the process of separation by liquefaction and suppuration occurs: such excision is not usually advantageous before the middle of the second week after burning. With earlier excision, apart from the considerable blood loss which may be entailed, difficulties are likely to be encountered in estimating the depth of destruction and assessing the ability of the underlying tissues to support skin grafts: although excision is carried out through a plane which shows freely bleeding vessels between fat lobules of normal appearance, inspection at a subsequent

dressing may disclose a fresh surface zone of further necrosis, with consequent loss of grafts. Excision in the second or third weeks is safer although by no means devoid of the same difficulty It is advisable, in all cases where extensive slough removal is to be carried out, to commence the operation by setting up a blood transfusion with several pints in reserve. Bearing in mind that the cutting of grafts will increase not only the blood loss but also temporarily the area of raw surface a limitation should be set on the size of the area that can safely be excised and grafted on one occasion this will depend partly on the general condition of the patient, but excision and grafting of anything over 20 per cent of the body surface is likely to be dangerous. When excision and grafting are carried out as a life-saving measure in extensive burns, it may be justifiable to excise deliberately the fatty subcutaneous tissue down to the deep fascial plane, in zones where this is readily practicable (e g. abdominal wall) this lessens hæmorrhage and provides a base on which grafts take more readily Blood loss can be reduced from limbs by the use of a tourniquet. The time factor in operations of this type is particularly important and much can be done to speed up an extensive procedure by teamwork certainly operations of this kind on burned children should be limited to an hour

Although a conservative attitude is advisable in the retention of severely burned limbs, there is nothing to be gained by delaying amputation of charred and disorganized limbs, with extensive muscle destruction, massive exposure of bones and joints, or gangrenous extremities. When it is evident that such a limb will be functionally useless, no time should be lost in removing it It is wise to suture the skin flaps loosely over a pack and perform final skin suture as a secondary measure. Modifications may have to be made in the design of flaps according to the local damage in order to provide cover for the end of the stump below-knee stumps covered entirely with free skin grafts are unsatisfactory and, faced with this prospect, it is better to amputate the limb through the thigh at the site of election.

Where sloughs have been allowed to separate spontaneously a granulating surface presents for grafting. Grafts should only be applied to a granulating surface in perfect condition, with minimal discharge a matt surface, crimson colour and a ready facility to bleed if lightly touched. The application of grafts to pale, hypertrophic, flabby and infected granulations is usually a waste of time and skin. A few days preparation with saline baths or the application of frequent saline soaks may improve the quality of the granulations too long, however should not be spent in preparation as the increasing fibrous proliferation and resulting indolence reduces the receptivity of the surface. Fresh granulations in good condition accept skin readily the grafts can be directly applied to the surface without the difficulties of hæmorrhage, but it is well to remove traces of grease by gently swabbing with ether as a preliminary Granulating surfaces which are judged to be unsuitable for direct grafting should be excised, preferably with a blunt scraping instrument (the rounded end of a metal ruler is excellent for the purpose). The granulations separate in a well defined layer leaving a smooth surface from which the initial free bleeding rapidly ceases following the application of warm packs.

Grafting Technique. Grafts may be cut with a simple razor (Blair) knife, the Humby modification with spacing roller or by mechanical dermatomes powered electrically or pneumatically which have largely displaced the more cumbersome adhesive drum dermatome. The use of the simple Blair knife requires the greatest skill, but unless the other instruments are quite unusually sharp and mechanically perfect the thinnest grafts

are most consistently cut with it. The mechanical instruments greatly facilitate the *rapid* acquisition of large areas of skin, including zones which may be inaccessible to the razor knife.

Localized burns are best covered with sheets of split skin the thicker the graft the less the liability to subsequent contraction and the better the ultimate quality Thinner



Fig. 114 Split-skin grafting of large raw surfaces in a patient with a burn involving 50 per cent of the body surface area. Nine donor areas whence skin has been taken with an electric dermatome are visible on the back. The skin has been applied as strips to the whole circumference of both legs and elsewhere. *Note the placing of sheets of skin over the popliteal fossa.*

grafts, however take more readily and in extensive burns there is usually the problem of making a little skin go a long way Thus when large areas have to be covered it is best to cut the grafts as thinly as possible, not only to increase the prospects of successful take but also so that the limited donor areas available may heal rapidly and be used again on a subsequent occasion. Over extensive raw surfaces, the skin grafts usually have to be spread out by application either in the form of isolated 1 cm. squares ("postage stamp" grafts) or better as strips 1 cm. in width (Fig 114). The closer the grafts can be placed to each other the quicker the initial healing, the less intervening scarring, hypertrophy and

contracture, and the less the likelihood of secondary operations being needed later Generally speaking the greater the area that can be covered at one sitting the better as the grafts are accepted by the raw surfaces more readily in the earlier stages nevertheless it is better to provide a reasonably complete cover for one zone if the skin supply is limited rather than to scatter widely separated grafts over an extensive area the intervening raw surfaces which will result are often troublesome to graft subsequently When it is impossible to resurface the burn completely at one operation, functional zones should be grafted first If it is judged that not all the raw surfaces are in suitable condition for the immediate application of grafts, the skin may be cut and stored, to be applied as a dressing a few days later without anæsthesia. Greatly increased initial cover can be provided by the use of homografts. Although there is evidence that these may survive for a longer period when provided by multiple donors, in the absence of a skin storage bank it may be more convenient to obtain the skin from an individual donor at the time of operation. The homografts are best arranged in strips alternating with autografts when the homografts necrose, creeping epithelial substitution by the autografts may permit healing with the development of raw areas of minimal extent.

Regional Considerations Relating to Primary Repair

It is not possible to describe here the elaborate reconstructive methods which may be required in the repair of the burned patient by plastic surgery However as the primary grafting may provide permanent skin cover or modify the later reparative work, a knowledge of the salient features of reconstruction of the various parts of the body is desirable

Trunk and Limbs. Even with efficient initial grafting subsequent contractions are liable to arise in the axillary antecubital, inguinal, and popliteal zones displacement of the nipple in young girls may be disfiguring and interfere with subsequent normal development. The primary skin grafts should be arranged in such a way that any intervening scars will not develop longitudinally across the flexor surfaces of joints, and wherever possible these areas should be resurfaced with large sheets of skin. Contraction is particularly difficult to avoid when more than one joint is involved adjacently in an extensive burn (e.g. shoulder and elbow) (Fig. 115) Some improvement in joint range occurs over a period of 3–6 months after grafting, and minor degrees of functional impairment are best left untouched during this period of resolution of the recent scar there is no point, however in delaying treatment when the range is grossly reduced, and further skin should be introduced at an early stage. It should be remembered that whilst young children will tolerate splinting of the joints in flexed positions by skin contracture for long periods, with complete recovery on correction of the skin shortage, in adults secondary articular and periarticular changes are likely to preclude reattainment of full range if the contracture is neglected. After 3–6 months residual degrees of contracture may be corrected either by means of Z-plastic procedures if the necessary length can be gained at the expense of width, or by creation of a defect at the point where release is required and the introduction of further skin. Although repair with split skin grafts is the normal method of obtaining primary cover in acute burns, occasions may arise where open joints or exposed bones on limbs may require the application of an immediate direct flap such a procedure necessitates the presence of an intact skin margin to which the flap may be sutured.

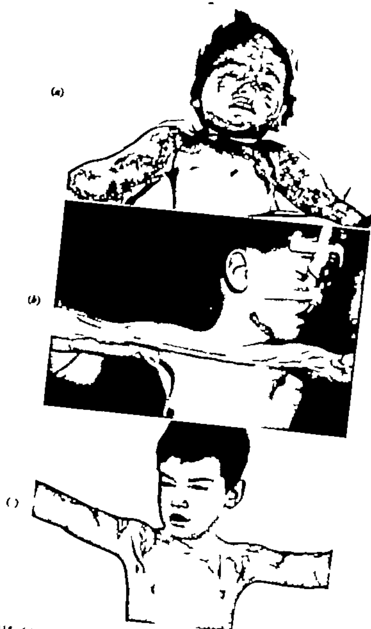


FIG. 115 (*a*) Deep flame burns of arms and upper chest (initial stage under exposure treatment) (*b*) T o years later I spite of adequate primary grafting, web-contracture has developed across the chest and upper arms from one ante-cubital fossa to the other (*c*) Immediate result of multiple Z-plastics carried serially the full length of the web.

The Hand. Initial œdema is minimized by slinging the arm in an elevated position. Dressings should be light and the fingers covered individually to allow early independent movement. Burns of the hand tend to fall into two classes, palmar and dorsal

(1) *Palmar Burns* These commonly arise in young children from grasping bars of electric radiators or similar hot objects, and lead to devastating flexor contractures or fusion of the fingers. They are best treated by excision at 10 days or more, with immediate grafting splintage is necessary in the first instance to immobilize the fingers and support the graft. The splint as initially applied should maintain the fingers in full extension splinting in this position may be maintained for 3 weeks in young children until the graft is stable in adults the fingers are brought into the position of function within 10 days. Following discharge from hospital an acrylic splint is worn at night for 3 months. Subsequent contraction is unfortunately not uncommon, and is treated by the creation of defects and the addition of further skin as indicated.

(2) *Dorsal Burns* This is the most common severe burn of the hand in adults, usually arising from flash, and leading if neglected to the following crippling deformities (*a*) flexed wrist (*b*) hyperextension of metacarpo-phalangeal joints and flexion of inter phalangeal joints, with shortening of collateral ligaments and the relaxed portion of joint capsules (*c*) proximal slipping of extensor hood with subsequent fixation, leading to impaired action of the intrinsic muscles, and (*d*) reversal of the normal concavity of the transverse palmar arch (Fig. 116). As these deformities are difficult, or in the most severe degree impossible, to correct subsequently the greatest care should be taken to prevent their development. The initial trouble occurs when the patient adopts the natural relaxed posture of greatest comfort the wrist is dropped, the hand being commonly allowed to hang flexed over a pillow This posture relaxes the flexor tendons and tightens the flexors prolonged œdema, slow healing, and sepsis together with damage to the extensor mechanism over the joint prominences lead to the established fixed hyperextension deformity but the deformity has been seen in superficial burns of the hand as a result of improper posture and œdema alone A volar plaster slab applied externally over the dressings holds the wrist in the position of function with 20° of dorsi-extension and slight ulnar deviation the splint stops short of the distal flexion crease of the palm to allow movements at the metacarpo-phalangeal joints, which should be encouraged from the start unless the joints are open. During the second or third week after burning, when the diagnosis of complete skin destruction is certain, the whole dorsal burn should be excised, with tourniquet control of hæmorrhage in all but the deepest burns there is a safe and satisfactory plane of cleavage immediately dorsal to the fascia overlying the dorsal space of Kanavel, and the dissection should be most carefully carried out at this level. The margins of the excision are trimmed to avoid subsequent straight scars in the neighbourhood of joints, and the raw surface covered with a split skin graft tailored to fit the defect and sutured marginally into position. The graft will take over viable tendon, but obviously necrotic tendons should be excised doubtful zones are best left. The hand is then dressed and carefully splinted in the position of function. Following the first dressing on the fifth or sixth day active movements are recommenced but it is advisable to retain the wrist splintage. Early skin cover minimizes the œdema and suppuration which accompanies natural slough separation, and prevents the resultant fibrosis with its attendant evil effects upon the function and nutrition of the hand. The use of pedicled flaps on the hand should be avoided whenever possible, and particularly over the palmar

surface occasionally however cover with a flap is required for very destructive burns with multiple open joints or exposed metacarpal bones, to retain a functional hand. Flexion deformities of interphalangeal joints which result from destruction of the overlying extensor mechanism should be corrected by arthrodesis in functional position as soon as the quality of the covering skin permits apart from the improvement in position gained, increased purchase by the long flexors is obtained in flexion of the metacarpo-phalangeal



FIG. 114. Burned hand showing typical hyperextension deformity. This hand is virtually useless, and the deformity although preventable, is difficult to correct when established.

joints, power being otherwise lost in hyperflexion of the distal joints. Dorsal webbing across the interdigital clefts is a common sequel this should be relieved by interdigital grafts, applied on stent moulds for initial fixation this not only frees the fingers and permits opposition of the thumb, but also restores the palmar concavity of the metacarpal arch and mobility of the metacarpal heads.

The Foot. Flap repair may be essential on the dorsum to save the foot in the presence of multiple open tarsal joints. On the sole, initial healing should be obtained with split skin grafts whenever possible pedicled skin, bulky and mobile, requires constant attention and usually some lifelong restriction of normal activity when applied over weight-bearing areas. It is surprising how well the relatively fixed free-grafted skin may

stand up to pressure on weight bearing areas, and undergo protective hyperkeratotic changes.

The Face Dressings in the first instance may consist of tulle gras, and this is best applied in separate pieces to cover eyelids, forehead, lips, nose, etc. with a light gauze mask applied over it. If early exudation is profuse a wool collar is applied to absorb this and the dressings may have to be changed frequently Early opportunity should be taken

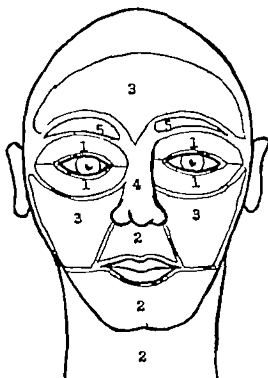


FIG. 117 Areas of priority for primary skin-grafting to achieve symmetrical repair of face.

to examine the condition of the eyes before œdema closes the lids and renders examination impossible for several days.

As it is possible that the primary grafts applied may form the permanent skin cover some care is necessary in the manner in which the grafting is performed if a harmonious result is to be achieved. The face may be divided into the following zones, each of which should be grafted with a separate but complete sheet of skin to give a symmetrical result in a total facial burn eyelids, upper lip, lower lip, and chin, nose, cheeks, and forehead. (Fig. 117)

The eyelids require first priority in grafting over burns anywhere else on the body owing to the dangers arising from exposure and drying of the cornea the next priority is the circum-oral region, to permit both eating and anæsthetic intubation. Initially in severe eyelid burns with destruction of the lid margins it may be impracticable to do more than lay a single sheet of Thiersch graft over the raw eyelid surfaces should a spontaneous tarsorrhaphy thus result it may be of some temporary advantage in providing

cover for the globe. With the onset of contraction of the graft, copious further skin must be added, sometimes on more than one occasion until full mobile cover is obtained. The technique of releasing ectropion is virtually a standardized procedure, a defect being created by a horizontal incision 3 mm. from the lid margin It is important in burns which are still in the contractile state to carry this incision well beyond the outer canthus and also past the inner on to the side wall of the nose the thinnest possible hairless graft (in the case of the mobile upper lid) is then applied on a stent mould which is partially buried in the defect by overtying with long marginal sutures. A considerable surplus of skin is thus introduced It is safe to remove the moulds by the fourth day (Fig. 118)

Apart from the provision of skin cover for the circum-oral region, opening of the angles of the mouth may be necessary at quite an early stage to release microstoma arising from contracture. The contracted skin and underlying scar at the angles of the mouth is divided for the required distance, and if necessary the oral sphincter divided through not more than half its width. The adjoining mucous membrane is then undermined for a short distance within the cheek and then advanced to fill the small defect.

Deep burns of the anterior surface of the neck present a very real problem, as the contracture which rapidly ensues, dragging the chin down to the sternum, may render anæsthetic intubation impossible Every attention should be paid to posture, both before and after grafting, the patient being nursed with the neck in extension. The application of skin grafts in the form of horizontally-disposed strips, exposing them to the air and keeping them dry from the start, may succeed when other methods fail from movement or infection. Difficult cases showing intractable contracture may require treatment with a flap transferred from elsewhere

Exposed cartilage of ear or nose that cannot be covered is best excised to permit rapid healing and to avoid the onset of a painful suppurative chondritis.

Free grafts over intact facial muscle permit greater mobility of expression in the final result and are therefore used in preference to flap repairs, except in the following circumstances (a) very deep destruction, with exposure of bone, or loss of the full thickness of lips or eyelids (b) for reconstruction of the nose when the cartilaginous portion has been lost and (c) less commonly as a late method of repair in patients who do not take free grafts well.

Initial healing of the nose has usually to be obtained by free grafts. If the destruction is relatively superficial, adequate repair may be achieved later by the replacement of the split skin cover with a Wolfe graft, drawn up alæ being turned down and released in the process. More extensive destruction requires rhinoplasty with a pedicled flap as the forehead is usually damaged recourse is made to an acromio-thoracic tubed pedicle based on the extreme tip of the shoulder whence it may be directly attached failing suitable donor skin in this region, skin has to be brought from further afield, on the wrist. As lining for the nose is generally provided to some extent by inturning the surrounding split-skin cover it is best to wait at least 3 months until the grafted skin has stabilized sufficiently for such a procedure to be carried out safely

Supervision is required until the contractile phase has passed, when a final "trimming up" can be carried out, with excision of junctional scars, release of minor pulls with Z plastics, the addition of eyebrow grafts, etc. It is important to maintain bilateral symmetry in the pattern of grafting in whole face burns, and above all to avoid a



FIG. 118. Technique of eye-lid grafting. (a) Ectropion of lower lid from contraction of primary graft. Incision shown, carried well beyond the canthi. (b) Thin Thiersch graft wrapped over a mould of Stent's composition about to be inserted into defect created. (c) Mould and skin tied into place.

heterogenous mixture of areas of flat free grafted skin interspersed with bulky skin flaps (Fig. 119).

Scalp. A problem frequently encountered, particularly in epileptics, is the exposure of large areas of cranial vault. If this is left untreated, slow sequestration and separation of the exposed bone takes place over a period of 6 months to a year or more. The healing process can be hastened by removal of the entire denuded outer table, exposing bleeding



(*a*) (*b*)

Fig. 119 Illustrating the importance of symmetry in facial repair and the difficulties encountered when planning has been haphazard. (*a*) Patient when first seen, after 16 operations elsewhere to correct facial deformities small areas of pedicled skin and free graft are distributed irregularly over the face, and apart from the fact that various deficiencies and contractures about the eyelids, nose, and mouth still persist, there is no cohesion in this repair (*b*) Correction involved recommencement of the repair almost from the beginning, in brief (1) regrafting of eyelids and upper lip (2) making use of an acromio-thoracic pedicle, forming the nose with one end and the right cheek with the other (3) advancement of neck skin on to left cheek to balance the opposite side, and (4) free eyebrow grafts. Final trimming of junctional scars not yet done.

diploic bone. This may be free grafted immediately or grafting may be delayed until the appearance of granulation tissue after an interval of 10–21 days. Multiple drill holes are unsatisfactory

Chemical Burns

These burns occur mainly in laboratories or in industry from accidental contact with a variety of substances, of which the more common are strong acids and alkalis, lime, and phosphorus, although the latter is mainly a wartime accident. When caused by liquids, the burn usually takes the form of localized splashes, with characteristic "trickle" marks The sloughs resulting from deep burns vary in appearance according to the causative agent as follows hydrochloride acid, yellow brown nitric acid, the yellow colour of

the xanthoproteic reaction sulphuric acid, dark brown phenol a white slough, the burn often being virtually painless owing to the anæsthetic properties of the reagent alkalis tend to produce pale macerated sloughs after a latent period Hydrofluoric acid, once it has penetrated the intact horny layer of the skin, which forms a temporary barrier exerts a prolonged and excruciatingly painful necrotising action on the underlying subcutaneous tissue causing extensive destruction which may go on for several days the skin slough is greyish purple in colour

It is customary to treat acid and alkali burns in general by appropriate neutralization with 1 per cent acetic (or citric) acid, or 5 per cent bicarbonate solution alternatively a buffer solution containing monobasic potassium phosphate 70 gm. dibasic potassium phosphate 180 gm., in water 850 ml. may be used to neutralize either Caustic soda burns may be treated by the immediate application of 5 per cent ammonium chloride. The appropriate neutralizing solution is usually kept at hand where there is constant risk of accident in industrial processes If the appropriate solution is not immediately available, valuable moments should not be lost in procuring it, but the burn should be treated forthwith by repeated flushing in running water Indeed, there is much to be said for the routine emergency treatment of these burns in this simple manner as it is possible that the heat developed in the process of chemical neutralization may do more harm than good. In lime burns, however on account of heat developed on solution in water efforts should be made to brush away or pick off the particles before wetting them oil or grease may assist this, and water is then directed in a continuous stream to carry off the local heat of solution Hydrofluoric burns should be treated by immediate immersion in warm saturated bicarbonate solution, followed by the application of a magnesium oxide and glycerine cream as soon as possible a 10 per cent solution of calcium gluconate should be thoroughly injected into around, and beneath the slough, under local or general anæsthesia. Phosphorus burns are washed repeatedly with 2 per cent copper sulphate solution, the burn being kept immersed in water until this is available It is wise to remove any clothing which might be contaminated, or re-ignition may occur as drying takes place.

Chemical burns in general are characterized by slow healing, with profuse fibrous and a tendency to hypertrophic scar formation. When the depth is in no doubt and the burn localized, there is much to be gained by prompt excision of the slough and of any "trickle" marks, with immediate grafting and where possible primary suture. The depth is often difficult to estimate initially where there is serious doubt, however the burn is almost always found by later developments to involve the full thickness of the skin.

Electrical Burns

Three factors have to be considered in the production of these injuries (*a*) arcing at the point or points of contact with the skin (*b*) the specific effects of conduction of electricity through living tissue and (*c*) the heating (Joule) effect of the passage of the current. The heating effect, dependent on the amperage passed through a given cross-sectional area, can be dismissed as negligible in the ordinary domestic electrical burn.

The heat developed in an electric arc (5,500–7,000°F) is formidable. Electric "flash overs" in switchgear sometimes produce quite severe flash burns in attendants near but not in contact with the apparatus, and when contact of metal implements held in the hand is made with the electrical source, the skin of the hand is occasionally seen to be coated

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with a veneer of vaporized metal. When the skin itself comes into accidental contact with a conductor the area of contact is usually imperfect, and arcing occurs at the surface, with the production of a localized but commonly deep burn the appearance is characteristic and unlike an ordinary contact burn. The edges of the burn are slightly everted, and surround a central base which is ragged, greyish, or charred, dry and firmly adherent. No blistering is seen in the skin surrounding this crater-like lesion. There may be multiple points of contact, and lesions in different parts of the body may represent points of "entry" and "exit" of the current. The heat generated at the surface is of such degree that destruction in depth may be considerable, and far more extensive than might be expected from the external appearance damage to important structures is particularly liable to occur where these are near the surface, as in the fingers, when tendon or digital nerve necrosis may occur from burns of an apparently insignificant extent.

The effects of electrical conduction on the tissues are twofold (*a*) stimulation of the nervous and muscular system, and (*b*) a specific necrotizing effect on the tissues in the direct pathway of the current. The clinical results depend mainly on the course taken by the current through the body Muscular spasm in the arms and hands may prevent the release of grasp, and thus aggravate the effects both of local arcing and of conduction. Passage through vital centres leads to interference with the vagus cardio-inhibitory and vasomotor centres, paralysis of the respiratory centre, and ventricular fibrillation. Jellinek states that the risk of sudden death depends to a marked degree on whether the shock is to any extent anticipated, or entirely unexpected in the latter case it is more likely to be fatal. Little is known of the pathology of the local destructive effects of the passage of current through tissue cells. The pathway taken by the current along a limb is liable to be capricious as judged by the damage left in its trail although there is some tendency for the current to follow the main neurovascular bundles, exploration of a severely burned limb may show some muscle groups to be gangrenous, whilst those adjoining appear normal late sequestration of bone is sometimes seen, and secondary hæmorrhage from large vessels is not uncommon. Gangrene of the hand or foot in burns of this severe degree may supervene as a result of direct damage from the initial local arcing or subsequent vascular thrombosis.

The degree of damage from conduction is related to the milliamperage of the current passed, which depends on the resistance of the pathway and the voltage applied major factors affecting resistance are the efficiency of contact with the conductor and the skin resistance both at point of "entrance" and exit" to earth potential or the opposite electrical pole, largely a matter of skin moisture. The minimum fatal current is stated to be 70–80 milliamperes (Alexander 1938), and alternating current is said to be more dangerous than direct. The local tissue damage may conceivably be due to irreversible electrolytic shifts in the cell and through its wall resulting from the temporary electrical polarization across it.

General treatment of the patient rendered unconscious from electric shock consists primarily in carrying out artificial respiration if necessary for a prolonged period of time, until the onset either of spontaneous respiration or of hypostatic staining and rigor mortis. Local treatment often presents a problem. Natural healing is extremely slow and the burn may appear unchanged for several weeks once healing is attained, however the scar even if extensive, is smooth and supple, as pointed out by Jellinek, and not

as a rule subject to hypertrophic changes or contracture. The best results are obtained by early excision and closure by direct suture, free grafts, or flap repairs as appropriate the dissection may expose nerves or tendons, and should therefore in the case of the extremities be carried out in a bloodless field, and by a surgeon with the ability to close the defect thus created, to provide satisfactory cover for any important structures which may be laid bare. Difficulties arise from the necessary preservation of nerves and tendons whose viability is in doubt, and which may subsequently slough the routine excision of electrical burns is not so simple a procedure as is sometimes suggested In really severe burns of the extremities it is wise to explore a swollen proximal portion of the limb even though the overlying skin is intact section of the deep fascia releases tension, and any gangrenous muscle-groups can be excised with some prospect of saving the limb from amputation later The institution of measures against tetanus and gas-gangrene infection is advisable.

Radiation Burns

The risk of the occurrence of ionizing radiation burns following therapy or diagnostic procedures depends on the dosage employed, its manner of delivery and the individual susceptibility of the patient. The injuries take two distinct forms, early (acute) radionecrosis, and late necrosis following chronic radio-dermatitis. The acute type develops as an immediate sequel to irradiation. Whilst minor damage to the skin gives rise to erythema, followed by desquamation, and recovery—the "normal" reaction, more severe damage is evidenced by local oedema, with violaceous discoloration and severe pain central sloughing occurs, often to considerable depth, and extending marginally to merge with a zone of more superficial damage. The slough is slow to separate, the marginal demarcation is ill-defined, and slow extension of the necrotic area may occur over a period of weeks. The subsequent phase of granulation in the presence of profuse fibrosis and endarteritis may last for months or years before unstable epithelialization occurs. Late necrosis occurs months or even years after treatment, either following a single heavy course of irradiation, or as a result of repeated radiation therapy of some chronic condition, applied as multiple small doses over a long period. The skin becomes indurated, fibrotic, inelastic, and shows multiple telangiectases through the thin epithelial layer it is devoid of hair and natural secretions, keratotic, and the local nutrition is impaired by endarteritis. In these circumstances some slight local trauma, such as sunburn, exposure to cold, or local infection, leads to necrosis, with ensuing ulceration and granulation, and local pain usually of extreme intensity It is sometimes difficult to differentiate between late necrosis and recurrence of neoplasm, and at times the two conditions co-exist carcinoma may also arise *de novo* on a basis of chronic radiodermatitis.

The treatment of the acute burn is initially conservative until the depth and extent of the damage can be clearly and as far as possible finally defined. The burn is less painful if sealed from the air with occlusive dressings application of any substance which might irritate the skin is avoided. In chronic radiodermatitis the faculty of local regeneration is severely limited and only excision of the whole involved area and its replacement by grafted skin hold any prospect of relief. There is usually an obvious plane of leakage between the fibrosed superficial tissues and the deeper structures but when the necrosis involves muscle or bone these should be excised and any sequestra removed Repair is

carried out with split thickness skin, or with flaps when the base is avascular The relief of pain following excision is immediate and complete.

Radiation Injuries in Warfare. The probable use of weapons exploded by the initiation of thermonuclear reactions in any future major conflict necessitates a brief consideration of the specific types of injury which are found in the casualties. Apart from blast injury both thermal flash burns and ionizing radiation effects are liable to occur in persons exposed over a surrounding zone, the dimensions of which are at the time of writing purely conjectural, being dependent on many variable factors, including the height at which the bomb is exploded, weather conditions, the degree of local protection and (more particularly with the utilization of the hydrogen fusion reaction) the mass of the weapon. The radiation element gives rise to ionizing radiation sickness, and experience in World War II and since suggest that a diffuse dosage of 1 000 r is probably always fatal and that probably 50 per cent of casualties who have received 400–600 r will die. The illness commences with nausea and vomiting, and the leucopenia is first evident 24 hours after exposure a white cell count below a thousand at this stage is always fatal After a latent period (2–3 days after high intensity irradiation, but up to 10 or 12 days in the case of lower exposure) various hæmorrhagic symptoms occur in association with the leucopenia, including melæna, hæmatemesis, epistaxis, bleeding from the gums, and purpura. Bacterial invasion and ulceration is a complicating factor in the mouth. Epilation occurs at the third week. Leukæmia is a possible late complication. Treatment, presumably after an initial sorting of the inevitably fatal cases from those with some possibility of survival, is symptomatic, involving nursing, blood transfusions, and the use of antibiotics to control infection until the leucopenia is rectified.

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CHAPTER VII

GENERAL ORTHOPÆDICS

NORMAN CAPENER

HISTORICAL

ORTHOPÆDICS is the division of medicine dealing particularly with the disabilities of form and function in the locomotor system. While the subject is predominantly surgical it also embraces preventive measures, by the detection of incipient deformity and disability it thus is specially linked with the social services similarly concerned Obviously those who practise orthopædics must have a regard for "the whole man" from a general medical viewpoint and be ready to co-operate with other workers having special interests in the same fields for example, public health, general medicine and its subdivisions, pædiatrics, neurology rheumatology and geriatrics, plastic surgery etc There are said to be certain basic principles of orthopædics, but these are not peculiar to it. It is, nevertheless, true that its practice has grown out of the idea of "physiological rest" or what should perhaps more properly be called *physiological control*

The name "Orthopædics" originated with Andry in 1741 and was applied by him to the treatment of deformity in children in particular the use of corrective appliances and remedial gymnastics. Thus the subject remained until the end of the nineteenth century and comprised a large part of general surgery until well into the twentieth century During the eighteenth century with the beginning of the Hunterian era in British Surgery great advances were initiated by the work of such men as Cheselden, Pott, the Hunters themselves and their disciples. With the introduction of tenotomy by Strohmeyer and Little, the first British orthopædic institution (The Royal Orthopædic Hospital) was founded in London in 1843 Further advance occurred with the general development of surgery following the introduction of anæsthesia and the control of sepsis, but it is of particular note that in the latter half of the nineteenth century these advances in surgery coincided with the more conservative teachings of John Hilton and Hugh Owen Thomas. The idea of physiological rest enunciated by Hilton, and its application by Thomas, were to have a profound influence upon the twentieth-century development of orthopædics as a special branch of surgery by Robert Jones in England and Robert Lovett, John Ridlon and others in America. Thomas s work arose in opposition to primitive and popular "bone setting" and against unenlightened surgery The greater influence of Robert Jones was due to his application of Thomas s ideas with understanding and persuasion, together with the employment of surgical principles. He was one of the first to advance rehabilitation by the therapies of work, education and other occupations, with the development of appropriate social services.

From being a specialty dealing with the disabilities of structure and function in childhood, orthopædics has come to include within its scope similar conditions in adults and, in recent years, most of the traumatic lesions of the locomotor system including fractures and dislocations—as such it has become the biggest subdivision of general

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surgery Indeed, it was the great concern which arose from the report on fractures by Robert Jones in 1912 to the British Medical Association and to his organization of fracture treatment during the 1914–18 war which did so much in Great Britain to stimulate the great advance in orthopedics which has since occurred, an advance which has been linked with social progress generally and with the work of voluntary organizations such as the Central Council for the Care of Cripples, with the foundation of which Sir Robert Jones and his co-worker Dame Agnes Hunt, were closely identified.

The historical background of orthopedics until the early years of the twentieth century has been well given by Sir Arthur Keith, in his delightful book "Menders of the Maimed" (1918) A more detailed history and bibliography is available in Bick's "Source Book of Orthopedics" (1948) In the English speaking world later work in the twentieth century is largely to be found recorded in the pages of the Journal of Bone and Joint Surgery and is epitomized in a special number published in 1950

Present day medicine with its many special departments of investigation and treatment paradoxically and necessarily demands greater breadth of outlook by those working in these special departments This is well seen in orthopedics, where the locomotor system is so closely concerned in the general metabolic processes and visceral activity of the whole individual. The orthopedic surgeon must, like a physician, consider his patients as a whole.

CLASSIFICATION AND ETIOLOGY

In classifying the disorders to be dealt with in the exposition of such a wide field as orthopedics, it must be recognized that existing classifications are not entirely satisfactory Hitherto it has been usual to consider conditions under such headings as *congenital developmental, metabolic infective traumatic* and *neoplastic* Purely chronological distinctions such as those implied by the terms *congenital infantile adolescent* and *senile* though sometimes convenient have little pathological significance. A regional or a systemic division has serious defect, for though a disease may have a characteristic natural history in one region, many of the diseases with which we are concerned affect many regions and several systems simultaneously If the purely etiological classification is retained it is no longer satisfactory though it may be convenient, to include within this a large group of lesions under the broad heading "congenital." Although the subject of congenital disorders is still somewhat obscure one may recognize that some lesions are transmitted by hereditary factors while others are acquired during intra-uterine life. Mendelian principles have greatly influenced our thought but recently the possibilities of environmental circumstances have received renewed interest as affecting the development of teratological abnormalities. Murk Jansen in the 1920's was one who considered that disturbances within the amnion occurring at different times during gestation were responsible for special deformities in the fœtus, according to the stage of development at which the influence was operative. Stimulated by Gregg's work upon rubella, other workers have emphasized that certain noxious influences applied to the embryo at various stages of development can produce deformations, the nature of which are predictable. The position has thus been stated by Ingalls From the welter of investigations has come an ever-growing list of teratogenic agents mechanical, thermal, electrical and radiant. They include light, density of medium, gravity and centrifugal force oxygen carbonic acid, water food, secretions of the ductless glands, salts, acids, alkalis, alcohol, ether

and tobacco The very diversity of teratogenic stresses suggests that any agent which can kill, can induce abnormal growth when acting in critical dosage at an appropriate moment of development." Ingalls himself has emphasized the important teratogenic influence of maternal anoxia, and doubtless would include radiation effects.

Amongst the conditions thus caused are those classed as dysraphism e.g. spina bifida, meningocele, anencephaly hypospadias but also include cardiac lesions (e.g. patent ductus) spinal malformations, phocomelia etc.

That intra uterine pressure phenomena play a part in the causation of such lesions as congenital talipes equino-varus and congenital dislocation of the hip has been stressed by Denis Browne the hereditary factors are strong yet it would seem likely that they operate through peculiarities of the amnion in fixing pre-natal posture. The commonest manifestation of such a condition being the early infantile scoliosis which is of postural character and is readily curable by simple techniques.

Having mentioned the factors of heredity and environment in the causation of the "congenital" disorders, one should note that these are not always apparent at birth or during early infancy Indeed, some are merely manifestations of a general constitutional disorder which may be assumed to be the late effects of inborn errors of metabolism. In this sense gouty arthritis, amyotonia congenita, or osteogenesis imperfecta are examples of greatly different types.

There are some so-called congenital disabilities which have a clear environmental origin in the hazards of birth itself for example, obstetrical palsies and torticollis. These might reasonably be included under traumatic lesions. Similarly with many of the examples of cerebral palsy although in this there is growing recognition of other possible environmental influences *in utero* causing cerebral and cerebellar arrest.

In infancy cases of developmental error appear in which the lesions are clearly due to nutritional deficiency This is well seen in rickets and scurvy but probably include such disturbances as osteochondritis juvenilis, though the nutritional factor is less obvious. These nutritional or metabolic disorders cause defective development of growing tissues, particularly of the skeleton, and may be related to other types of general disorder of endocrine origin, in which the inter relation of the pituitary adrenals, gonads, the thyroid and para-thyroid glands in various degrees is deranged. The lesion of the spine in cretinism is an example but is not peculiar to this disease for there is a similar disorder of development in the spine in the congenital disorder chondro-osteo-dystrophy (Morquio-Brailsford) Amongst the disorders of the fœtus or new born are certain neoplastic conditions which would seem to be congenital In this group belong the neuroblastic tumours of infancy which represent a disordered neurone development of embryological origin.

There are many other ways in which the etiology of bone disease is difficult to apportion between one and another of the etiological factors of developmental error metabolic disorder and neoplasm. For example parathyroid tumours produce in bones a developmental or metabolic disturbance due to fundamental disturbances of calcium metabolism. Somewhat similar disturbances in bony structure are related to disorders of body chemistry the result of nephritic disease. Furthermore in parathyroid disease, lesions appear in bone which precisely resemble the single osteoclastoma which so far as we know is neoplastic.

Infective lesions often noted as acute or chronic can no longer be distinguished

usefully in this way Acute pyogenic infection may be extremely slow in development.
Though due to the same invading organism, in one case the disease may be of fulminating
type with an acute osteitis and septicæmia, while in another it may develop slowly and
only appear years after its origin, as a chronic encysted abscess as described by Brodie.
Such varying pictures which may occur in the natural history of bone infections is now-
adays likely to be more confusing with the varying effects upon infective disease pro-
duced by the antibiotic drugs. Tuberculosis usually regarded as a chronic type of bone
disease can be manifest as a quite acute lesion. Chronic deforming arthritis often re
garded as infective is now recognized as much more frequently a metabolic disease
The etiological factor of trauma is equally complex in its type and in the effects which
it produces. Primarily it results from any external agent such as chemical, physical or
mechanical force The common influence relating to the trauma is, of course the in-
fluence of gravity or the velocity of moving objects. Force may be slow in action and
therefore relatively static or it may be sudden and thus dynamic. Force applied from
without produces lesions not only by its direct application, but includes the reaction of
forces within the body It includes the reaction of such forces upon tissues that are
pathologically unsound as, for example, in "stress" fractures, but also includes the so-
called pathological fractures seen in osteomyelitis and neoplasms. In such trauma the
violence is unimportant by comparison with the underlying lesion. It should, however
be realized that all fractures are stress fractures—for the word stress in its mechanical
sense merely means the direction in which any force is applied.
Injuries to bones and joints invariably involve injuries to soft tissues to a secondary
and maybe lesser extent. Not infrequently the soft tissue injury is of greater importance
than the fracture or dislocation, and if not treated properly can result in a greater element
of disability than that of the imperfectly treated bone. Amongst such secondary lesions
those of nerves and vessels provide some of the most serious complications. Injuries
complicated by infection may result in general constitutional disorders greatly over
shadowing the local trauma. Equally serious are some of the more violent reactions to
trauma as seen in shock, hæmorrhage and the disturbance of renal function and electro-
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Difficulties of classification can be illustrated by benign neoplasms of bone. In the
first place the simple exostosis or ossifying chondroma is difficult to isolate from de
velopmental disorders such as diaphyseal aclasia. This, which has a strong hereditary
background, is not easy to separate from dyschondroplasia in which this element is less
clear With the latter is allied the peculiar multiple enchondromata of the digits which
should be considered, nevertheless, as a separate phenomenon. These lesions, however
behave somewhat as neoplasms and yet often have a monomelic or hemiplegic distribu-
tion which has suggested that neurological disturbances play a part. The neoplastic
characters of chondromata may range between the essentially innocent ossifying chon-
droma or the diaphyseal enchondroma to the very malignant chondro-sarcomata and
the border line is sometimes impossible to draw Some chondromata of the pelvis,
large in size and histologically innocent, possess the power of direct metastasis through
the tributaries of the inferior vena cava. This hazy borderline between developmental
and neoplastic disorders is repeatedly found in bone and joint pathology The synovio-
mata by their title suggest neoplasms, yet it is difficult to draw the line between this and
monarticular villous arthritis or multiple intra-articular osteo-chondromata.

From what has been stated above it will be seen that it is no longer possible to give an analytic classification which places etiology in clear cut compartments At the same time there is now a tendency to associate apparently isolated conditions into integrated groups and to recognize common factors, e.g. Siwe Letterer s Disease, Eosinophyllic granuloma and Schiller-Christian Disease. Another interesting grouping has recently been made by McKusick who has brought together as allied heritable diseases of connective tissues Osteogenesis Imperfecta, the syndromes of Marfan (Arachnodactyly), Ehlers-Danlos, Hurler (Gargoylism) and Pseudo-xanthoma Elasticum.

THE DEVELOPMENT AND VASCULARITY OF BONE

We have already noted the purpose of orthopædics in the preservation and restoration of structure and function in the locomotor system. It was John Hunter who was one of the first to emphasize that structure was an expression of function neither can be considered separately by the orthopædic surgeon in his reconstructive work, the whole of which must be based upon a sound understanding of the development of tissues, their microscopic structure and function as well as the inter-relation of tissues within organs and the recognition that the structure of bones, joints, muscles, tendons and peripheral nerves are indeed organs, the proper integration of which with other tissues and organs is vital and the knowledge of which is essential in understanding their pathological derangements and the problems of growth and repair

In particular awareness of the normal vascular arrangements in bone must illuminate all consideration of bone pathology Only thus can appreciation be given to the problems of necrosis, osteoporosis, sclerosis, sequestration, erosion and other features of osteochondritis, osteomyelitis, arthritis and arthrosteal tuberculosis.

Embryologically the primordial shape of bones is determined by inherent properties. As shown by the tissue culture experiments of Honor B Fell, an embryonic bone will grow to a recognizably characteristic shape even when separated from all its normal surroundings The moulding of bones into their adult shape is, however dependent upon the forces of function which are brought to bear Such influences are well seen in the infantile femur where the characteristic primordial pattern seen at birth is modified by weight bearing and muscular activity so that the relatively valgoid position of the femoral neck to its shaft is reduced. Where, however muscular force is defective as, for example, in early infantile paralysis with loss of the hip abductor muscles, then this valgoid tendency is maintained and maybe increased.

Embryologically the condensations of mesenchyme from which is formed the skeletal structure are differentiated into hyaline cartilagenous masses between which articular discs of mesenchyme remain until a central cleft is formed which provides the later joint cavity Ossification commences first as calcification in the centre of each cartilagenous unit. This is invaded by blood vessels and bone forming cells from the periosteum and these carry on the process of ossification.

The details of this complex process need not be elaborated here, but the relation of vascular tissue to the ossification of cartilage should be stressed. Repeatedly in pathology there is found a comparable association, or rather an antagonism between vascular tissue and cartilage. This antagonism in varying degree leads to erosion or ossification.

The process of ossification is a function of connective tissue cells differentiated to form osteoblasts. Any primitive connective tissue cell in the right conditions even if

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The process of ossification is a function of connective tissue cells differentiated to form osteoblasts. Any primitive connective tissue cell in the right conditions even if

away from normal bone-forming tissues may behave thus. This is the basis of ectopic bone formation as may be seen in some abdominal scars and elsewhere. This phenomenon was studied experimentally by C. Huggins of Chicago, who demonstrated the capacity of epithelial cells from the bladder and other urinary passages to stimulate bone formation when placed within connective tissue planes such as the rectus abdominis muscle. The metaplasia of connective tissue cells into osteoblasts appeared to be related to the secretion of phosphatase by the epithelium.

The antagonism between cartilage and vascular tissue is well seen in its different types in both rheumatoid arthritis and osteoarthritis. In the former the inflammatory changes in synovial tissues with the hypertrophy of its arterioles produces a vascular granulation tissue which, growing into the margins of the articular cartilage, produces characteristic areas of erosion. Precisely similar changes occur in the marginal destruction seen in tuberculous joints. In osteoarthritis while avascularity and bony sclerosis results in erosion of articular cartilage upon weight bearing surfaces through the mechanical effect of friction, nevertheless, in the non-pressure areas, as Trueta and his associates have recently shown, increased vascularity leads to the overgrowth of bone, causing osteophyte production which may replace and expand upon the surface of the previous hyaline cartilage as well as extending beyond its margins.

The relationship of joint cavities to the primitive mesenchymal articular discs is possibly of importance, as discussed by Bennett in the types of cellular structure which may be found in synovial tumours. Any of the normal skeletal elements may be encountered in such neoplasms.

For a thorough background study of the physiological histology of the skeletal and other connective tissues, the reader is referred to le Gros Clark's standard work upon the tissues of the body Further details are also given in the sections of the present work dealing with General Pathology and General Disorders of the Skeleton.

CLINICAL INVESTIGATION

As in every department of medicine the investigation of a clinical problem must start with a detailed history of the patient's symptoms and an assessment of the background of his life It is not necessary here to specify the details of history-taking which are common to all branches of medicine. Nevertheless, one should emphasize the need critically to bring to the fore of the enquiry basic features of the patient's symptoms, their origin and evolution. Essentially we have to investigate disturbances of sensation and of motor function with abnormalities of appearance and of general health associated with the derangements of the locomotor system. In an orthopaedic case the leading features about which the patient complains are pain, deformity loss of movement, weakness and instability Though one of these may be the dominant feature, rarely are they isolated. The clinician's problem is to correlate one with another objectively in the elucidation of the underlying disorder

The need to conduct a careful enquiry into the whole background is nowhere better seen than in orthopædics. It must include a consideration of the family and the community in which the patient lives his social status and occupation. These are of more than incidental interest or diagnostic importance for upon them may depend the plans of a long and expensive campaign of physical and surgical treatment associated with or followed by procedures leading to rehabilitation. Completion of such plans

may be determined by the grasp of the whole problem obtained during the initial observations.

The consideration of the structural and functional disability and its evolution and treatment must be illuminated by an awareness and assessment of the patient's psychological state. In adult life a large amount of locomotor disability is a manifestation of vulnerability to stress, physical or psychological which either alone or jointly with injury and disease, plays such a large part in the disabilities of modern life. The mentality of the individual compounded as it is of hereditary traits and environmental circumstances, has to be considered, not only in its etiological effects but also in its influence upon treatment and obversely in the manner by which it may be affected by the disease and its treatment.

In the consideration of the disabilities of childhood a complete history of the child's physical development from birth is necessary. Furthermore, it should include information upon the mother's ante-natal health.

General Examination

The locomotor system is an entity and there are few of its lesions which do not in some way affect the general physical structure of the individual or are not themselves local manifestations of a general disorder. While, therefore, attention at an early stage of examination may be directed to the local symptoms and signs it is advisable sooner rather than later to observe the whole constitutional state of the patient, his posture and gait, and to note his psychological characters. Much valuable information may be gleaned from the first glance at the patient, his size, weight, gait, demeanour, expression, tone of voice and handshake. His mental processes may be assessed from his discussion of symptoms and answers to questions. Nevertheless, there are few occasions in which it is not to the patient's advantage for the orthopædic surgeon to make a complete physical examination not only of the locomotor system but also of the entire individual.

Posture and Gait

Human posture though a "static" feature in a mechanical sense, is not stationary. Posture is constantly variable and normally the mean variations though frequent are small in degree. A wider habitual divergence from normal posture is indicative of degeneration and is well seen in lowered states of physical and mental well being and fatigue. It is necessary to have an appreciation of normal human posture, its probable evolution from anthropoid types and its tendency under stress, and degenerative states to revert to such less erect types.

Discussion of posture and its control is one of the happy hunting grounds of the eccentric and the charlatan. Too often normal posture has been regarded as all important as the determining cause of good health; such consideration pays scant attention to good posture as being a reflection of normal health. Nevertheless, it must be recognized that study of the evolution and defects of human posture is of practical value.

The fœtus in utero though having its limbs and spine folded in flexion, exercises far more than is usually recognized, excepting by the woman who is bearing it. The fully extended state is however probably limited. Those flexion muscles which have not had the normal stimulus of extension for a time remain short after birth. This is well seen in the hip where there is at birth fixed flexion or limited extension. Willis, for example,

has noted the part which extension of the hips, during "swaddling and diapering," plays in extending the lumbar spine. Wheeler Haines has shown that muscles grow in length according to the tension to which they are subjected. The process of extension of the spine, hips and knees in early infancy therefore stimulates the necessary lengthening of the flexor muscles, and proceeds until walking is fully established, but even then in

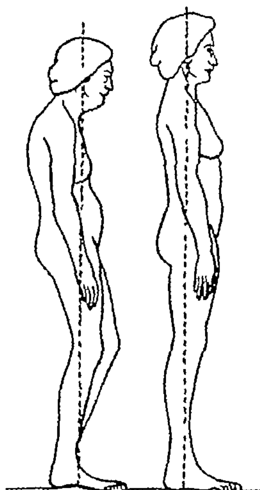


FIG. 120 *Good and Bad Posture.* The photographs of which these are tracings were taken in quick succession. The model was asked to "slouch" and to "be alert." Character and posture are somewhat related

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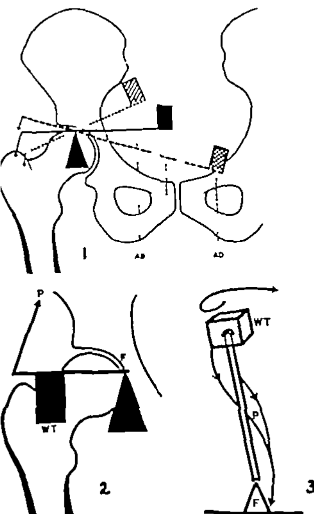


FIG. 121 (1) The leverage in the weight bearing hip joint. In adduction the centre of gravity is displaced away from, and in abduction towards, the joint. In the former muscular force and body-weight leverage are increased proportionately and in the latter are reduced. Body-weight × leverage plus muscle power × leverage is the measure of the pressure upon the femoral head. The illustration which is diagrammatic emphasizes the evil effects of adduction and of femoral neck shortening.

(2) The leverage at the hip in free movement of the lower extremity The length of weight leverage is shorter than the muscle power lever except when the limb moves into abduction. The pressure upon the *fulcrum will be relatively small.*

(3) Body-weight is moved forwards not only by muscles acting around the centre of gravity but by muscular propulsive effect transmitted through the femoral shaft from below and acting upon the pelvis through the acetabulum.

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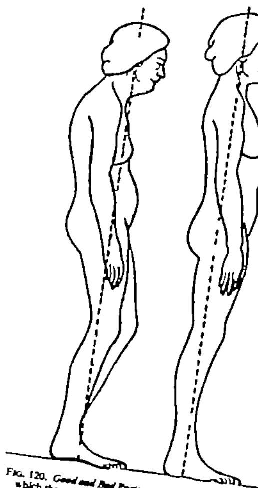
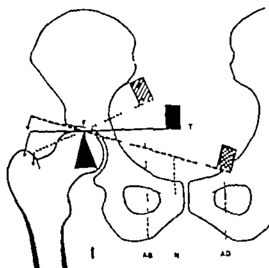


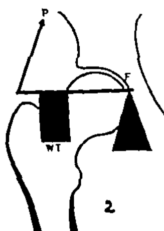
FIG. 120. *Good and Bad Posture.* The photographs of which these are tracings were taken in quick succession. The model was asked to "slouch" and to "be alert." Character and posture are somewhat related.

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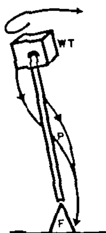


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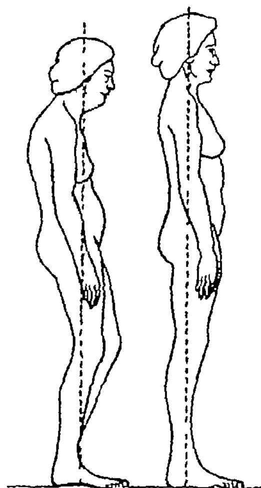
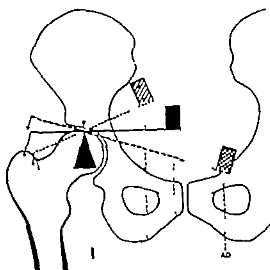


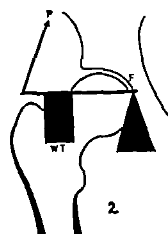
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Normal posture then is achieved to a large extent by extension of the knees and hips. With extension of the hips the first effect in infancy is to cause extension of the lumbar spine but, as the process proceeds still further by the extension or backward rotation of the pelvis, so a reduction of lumbar extension occurs.

In this evolutionary process of extension to the erect posture a shift in the centre of gravity has occurred with relative shortening of the forelimbs and lengthening of the lower extremity In the standing individual the centre of gravity is found within the pelvis on a line approximately between the level of the hip joints and the level of the lumbo-sacral joint. *Taking this to be nearly in front of the second segment of the*





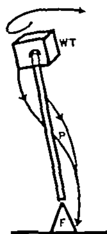


FIG. 121 (1) The leverage in the weight bearing hip joint. In adduction the centre of gravity is displaced away from, and in abduction towards, the joint. In the former muscular *force and body-weight leverage are* increased proportionately and in the latter are reduced. Body-weight × leverage plus muscle power × leverage is the measure of the pressure upon the femoral head. The illustration which is dia*grammatic emphasizes the evil* effects of adduction and of femoral neck shortening.

(2) The leverage at the hip in free movement of the lower extremity The length of weight leverage is shorter than the muscle power lever except when the limb moves into abduction. The pressure upon the fulcrum will be relatively small.

(3) Body-weight is moved forwards not only by muscles acting around the centre of gravity but by muscular propulsive effect transmitted through the femoral shaft from below and acting upon the pelvis through the acetabulum.

sacrum it is constantly variable in standing, walking or running with the swaying and elevations of body mass, as will be described later One should recognize, however that the centre of gravity is the meeting point of force from above and reactionary force from below Its control is fundamental in all human activity and as the meeting point of forces, the articular structures in its neighbourhood are sites of special vulnerability In order to maintain balance around this point all *actions of the body are performed in torsional* or spiral patterns. In fact this may be regarded as a necessary characteristic of all animal locomotion. It is, however well seen in the swinging of the arms and the movement of the pelvis in walking, in the twist of the body of the cricketer or golfer in the strokes

of the tennis player and the use of fork or spade by a labourer From many points of view the centre of gravity may be regarded as the functional "focus" of the human body

The process of extension of the lumbar spine, hips and knees advances by adolescence so that body weight is nicely balanced normally over the centre of the hip and knee, with a tendency for the line of the centre of gravity to come behind the axis of the hip joint and in front of that of the knee Thus balance of the body as a whole is maintained by the minimum of muscular action and this explains why some patients with very extensive paralytic lesions in the lower extremity are able to walk without aid providing progression is maintained upon level surfaces. It is commonly assumed that in normal standing the individual maintains position through the stress of body weight upon the anterior ligaments of the hip and the posterior ligaments of the knee It is probable that this is only the case in paralytics and in those in whom the control of the postural musculature is habitually defective

Fresh information upon the action of muscles in the maintenance of posture has recently been given by the electro-myographic studies of Sewell. The fact that minimal muscular exertion is required in the posterior spinal muscles for maintaining erect posture has been confirmed. It has also been confirmed that in forward flexion of the spine those muscles come into strong action to control the forward movement. In addition he has shown most strikingly that at the end of full forward flexion the whole strain of maintaining the position may be thrown upon other tissues, for then there is a complete cessation of activity in the erector spinæ group.

The essence of good posture is the maintenance of poise. The balance that is involved is not only of body weight upon joint surfaces, but of muscular activity around weight bearing joints so that a position is held with the minimum of muscular exertion and with no stress upon the ligaments which control hyperextension.

In studying posture one concludes that the mental stimulus to function is more important than the passive assumption of a supposed normal static posture. Nevertheless in most animals—human and otherwise, in varying degrees behaviour patterns are innate and traditional. Education, including that which is physical, therefore has an important part in aiding the development of proper mental stimuli

Gait

The orthopædic surgeon must be able to recognize the significance of abnormal gaits a matter that can only be mastered by the constant study of patients. As with posture, every individual has his own features which vary as much as does handwriting and similarly is an indication of character and health. Normal gait is a complex movement upon which some interesting studies have lately been published by Inman and his associates. They have described the determinants of normal gait which permit the human centre of gravity to follow a smooth pathway through space. It is obvious that the less this is distorted and the less that body weight must be elevated in order to achieve progress, so the less is energy expended Saunders, Inman, and Eberhart (1953) have shown how the movements of the pelvis, hip, knee, ankle, and foot convert what might be a jerky gait, in which the centre of gravity would pass through a series of arcs of high amplitude, into a smooth sinusoidal curve of low amplitude having lateral deviations which convert the curve into a spiral (Fig. 122). The determinants are those of pelvic rotation on a vertical axis, pelvic tilt, knee flexion, ankle and foot flexion, and obliquity

of the femoral shafts. From our particular point of view it is worth recognizing that in the stance phase of walking, pelvic rotation involves external and then internal rotation of the hip joint and pelvic tilt involves hip adduction on the weight-bearing side. The effect of pelvic rotation and tilt with knee flexion is to give the effect of a longer lever with a shorter stride the total effect of all the determinants is economy of energy Conversely any circumstance increasing the amplitude of movement is expensive Pathological variations in gait may roughly be analysed as resulting from pain deformity loss of muscular power and co-ordination, loss of movement and instability They involve alterations of rhythm, range and ease of movement. Protective gait may

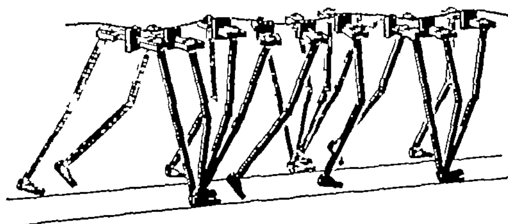


FIG. 122. *The Determinants of Normal Gait* This illustration sums up all the features of the hip joint movement in walking which are dealt with in detail by Saunders, Inman and Eberhart (1953).

involve avoidance or shortening of the time of weight bearing, it may be associated with diminished excursion in one or more joints of the lower extremity or with a rigidity of movement. The gait of deformity may result from altered alignment or balance the failure to complete a normal joint movement and the necessity for other joints to make greater movement in compensation, e.g. in flexion deformity of the knee. Loss of muscular power which may be relative where it is due to partial atrophy or absolute where there is paralysis—alterations in rhythm and balance are prominent. The grossest disturbances of balance are seen in cases of gluteal muscle paralyses in which body weight cannot be sustained on the affected limb without displacement of the trunk laterally over the paralysed side A relatively simple disturbance of rhythm is exemplified by paralysis limited to the dorsiflexors of the foot, when the whole limb is raised by increased flexion of the knee to clear the ground by the dropped foot coming forward. Equally characteristic is the slapping gait heard in patients with a paralysis limited to the tibialis anterior when the power of the remaining extensors of the toes are sufficient to lift the forefoot when the limb is raised, but are not sufficient to sustain the pressure of body weight when the heel is on the ground at a time when normally the tibialis anterior controls the downward excursion of the foot against gravity Defects in co-ordination seen particularly in upper motor neurone lesions may be manifestations of spasm, muscular rigidity ataxia, tremor or athetosis.

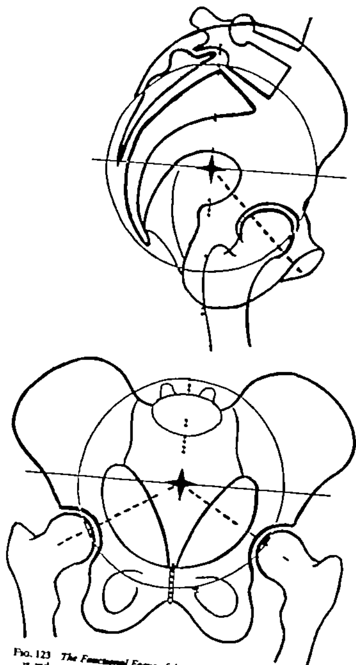


FIG. 123 *The Functional Focus of the Body.* The centre of gravity is indicated by a star with radiating vertical and horizontal lines. A circle shows the close relation of the lumbo-sacral and hip-joints to this focus of stress.

Major Symptoms

Pain. While pain is the dominant sensory stimulus it may be accompanied or replaced by heat, coldness, paræsthesia, hyperalgesia analgesia and anæsthesia. The presence of these other sensory disturbances at sites which are the same as, or different from, pain may be important diagnostic aids.

The anatomical pathways and the physiology of pain is outside the scope of this work. A useful summary is that of Kellgren (1955) Certain illustrative examples from orthopædic practice follow

Superficial Pain. Any noxious stimulus applied to surface tissues produces sharp pricking or cutting pain as seen in a needle prick or the presence of a sharp foreign body under the skin or a focal inflammatory lesion of the skin. Similar pain is produced by pressure upon the skin when it is compressed between an abnormal prominence deep to it and some external structure such as the ground or a shoe, as may be encountered in deformities of the feet. Similar sharp pain may be found when inflammatory disturbances affect the periosteum or synovial tissues of superficially placed bones or joints. Such pain is usually accurately localized to the part affected.

Deep Pain. This has widely different significance arising as it does from the deeper tissues including the viscera. Frequently in the more acute forms, it has constitutional effects apart from those of any general constitutional disease with which it may be associated. Such pain may vary from a dull ache to deep boring pain of extreme intensity and is particularly liable to be "referred" segmentally through the pathways of the spinal cord, or peripherally through the peripheral nerves where the lesion affects the nerves themselves or their roots. In abdominal surgery such reference of pain from visceral disease is well recognized. Similar segmental distribution is to be noted in the painful knee occurring in disease of the hip joint. Similar associations must be borne in mind in the consideration of chronic backache associated with visceral disorders.

Pain of peripheral nerve distribution is sometimes difficult to differentiate from pain of root or segmental origin, as for example in lesions of the sensory distribution of the ulnar nerve. In this direct irritation by osteoarthritis or a valgus deformity of the elbow joint, anæsthesia is of a limited extent in the lower part of the distribution of the eighth cervical and first thoracic area, and the motor loss is of the ulnar intrinsic muscles, whereas in a lesion of the same cervical roots at the thoracic inlet (as for example in Pancoast's tumour) the sensory loss includes also that of the medial antebrachial cutaneous area but the motor loss may at first only involve the thenar muscles of median innervation. In the ulnar nerve also the situation is further complicated by the presence of variants in the sensory and motor distribution which may take on more or less of the area supplied by the median nerve. Both the ulnar and median nerves provide other interesting problems in the distinction of segmental pain as, for example, in the relatively common *carpal tunnel compression* of the median nerve and in the ganglia which may cause pressure upon the deep branch of the ulnar nerve in the palm.

Central Pain. As seen in thalamic lesions is not often encountered in orthopædic practice, but it may be found as a troublesome feature of certain cases of hemiplegia of cerebral vascular origin, and has been described as a late sequel in patients upon whom antero-lateral chordotomy has been performed for intractable pain in osteoarthritis of the hip.

Psychogenic Pain. In orthopædic practice this probably is most frequently thought of as a hypersensitivity to stimuli arising from peripheral lesions. "The suspicion that pain is psychogenic may arise from, but must not be solely based on, the negative fact that there is no organic disease commensurate with the severity of the complaint. There must be positive evidence of psychological abnormality before a diagnosis of psychogenic pain is made" (Cohen 1952). Nevertheless one is bound to note under this heading the pain that is conditioned by impending litigation and the hope of pecuniary or other benefits.

Local Effects of Deep Pain. Amongst these must be considered muscle spasm which limits the movement of the affected part and may cause a "contracture" sufficiently marked to be called a "deformity" Long continued pain, especially if it is of arthritic origin, reflexly causes atrophy of neighbouring muscles and thus an element of weakness.

Pain of Special Type

(*a*) Neuralgia Paræsthetica. Such pain is an example of many other types of root or plexus pain where nerve units may be compressed or angulated and in which sensory disturbances may be isolated or may be associated with motor or reflex dysfunction, e.g. intervertebral disc protrusions with root compressions, angulation or compression of branches of the brachial plexus at the root of the neck, etc.

(*b*) Pain in Spinal Intra thecal Lesions. Apart from the pain of intervertebral disc protrusions the orthopædic investigator should have in mind the intra spinal lesions, particularly neoplasms. In such cases the intensity of pain and the persistence of it at rest may be clues to the nature of the trouble for which examination of the cerebro-spinal fluid and other special investigations may be conclusive. The differentiation of hysteria from such cases is occasionally very difficult for the morale of a patient with intra thecal tumour pain may become much depressed.

(*c*) Pain of Vascular Origin. This is dealt with elsewhere in this work but there are special examples commonly found in orthopædic practice and which should be noted here.

Causalgia is due to a hyperexcitability of all modalities of sensation an intense pricking hot pain is felt in the peripheral distribution of a damaged nerve. It is not infrequent in lesions of the median nerve and is common in association with the end bulbs of cut nerves particularly in amputation stumps and thus may aggravate the symptoms of a "phantom limb" The condition is related to fibrosis of nerve endings and local vascular irritability

Intermittent claudication due to obstructive arterial disease, and consequent defective metabolic activity in muscles, may be the explanation of pain on exercise and referred to the foot and calf

Sudek's post traumatic atrophy occurring in a certain susceptible type of patient usually with a recent injury to the hand or wrist, is a vascular phenomenon related to arteriole dilatation and interstitial fluid exudation. It causes a highly sensitive painful swelling of skin and soft tissues and is associated with de-ossification of the skeletal elements.

Deformity

The term deformity" is applicable to any abnormality of shape or posture of the body or its visible parts. Variations due to atrophy or hypertrophy local swellings due

to inflammation or neoplasm swellings of a whole limb due to vascular or lymphatic disease all of them strictly are deformities. Generally however the term is applied to abnormalities of shape and posture of the spine and limbs and these should be divided into two classes

(*a*) DEFORMITIES OF POSTURE in which the part is held in a position within the normal physiological range. They are due to such circumstances as

(i) Muscle spasm

(ii) Shortening of muscles.

(iii) Contracture of other soft parts including ligaments, joint capsules and skin.

Muscular shortening may result from muscular spasm, it may be the result of myositis and it occurs as part of the degenerative change found in peripheral nerve injuries and poliomyelitis. Such contractures if occurring in children have a greater effect in producing secondary adaptive changes in other tissues and they result in true deformations as is well seen in scoliosis. Muscular contractures appear to be particularly prone to occur in muscles spanning more than one joint, e.g. the rectus femoris in the thigh or the gastrocnemius in the calf The differentiation of such contractures may not be readily detectable unless special care is taken in clinical examination.

Postural defects of this type may be seen in the evolution of bone and joint disease before structural damage has occurred. They may also be seen as secondary manifestations of visceral disease when the muscles of the spine or trunk are affected reflexly by a disease in their vicinity for example, psoas spasm resulting in flexion deformity of the hip joint.

(iv) Fixation of joints by ankylosis.

(*b*) STRUCTURAL DEFORMITIES which produce positions of joints which are not within the normal range. Abnormalities of bony structure, of articular surfaces, of ligaments, all of which may be aggravated by muscular activity the influence of gravity and the combined effect of these when the periphery of the limb is fixed to or is resting upon an external object. Deformities of this structural type may be classed as hyperflexion or hyperextension if in the anteroposterior plane in the case of the spine, *kyphosis* and *lordosis* are terms applied respectively to each of them. If the deformities give rise to prominences medially or laterally they are referred to respectively as *valgus* or *varus* deformities. Occasionally in such cases the deformity is more obviously one of hollowing or concavity If on the medial side it is called *varoid*, if on the lateral side it is *valgoid* In the spine lateral deformity is *scoliosis* but it is never a pure lateral deformity for some rotation is a necessary accompaniment. To scoliosis is often added a kyphotic element. As will be seen later spinal deformity may be compensatory to other deformities especially of the hip and lower extremity It is then usually of the postural type. *Torticollis* is a special type of cervical scoliosis commonly due to muscular contracture (of the sternomastoid). It is associated with cranial scoliosis and facial asymmetry In the elbow an increase of the carrying angle is referred to as *cubitus valgus* A reduction of the carrying angle is *cubitus varus* In the wrist *carpus valgus* is seen as a congenital anomaly due to a short radius which may also be caused by epiphysial disturbance, the result of injury or disease In the fingers of arthritic patients many complex deformities may be seen those in the varus direction are often referred to as ulnar deviations.

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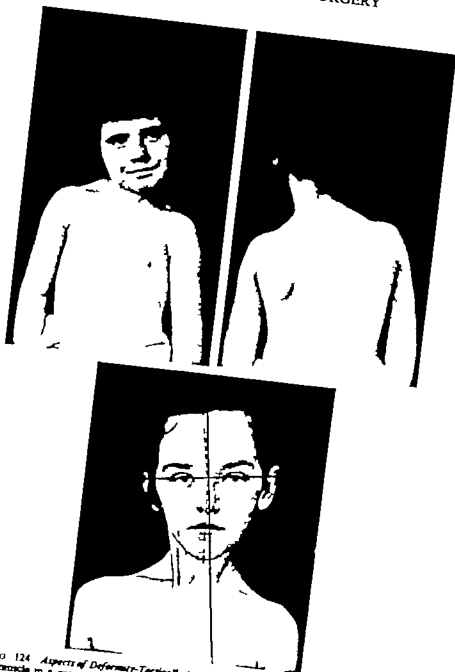


FIG 124 *Aspects of Deformity—Torticollis* (*a*) Contracture of the sterno-mastoid muscle in a growing child leads to spinal and cranial scoliosis—a structural adaptation.

From the clinical viewpoint deformities of the hip whether they are postural or structural have a special interest by reason of the method by which they may be disguised by compensatory movements of the pelvis and lumbar spine so as to maintain a functional weight bearing position for the lower extremity alongside its fellow. To achieve this parallelism of the two limbs, and to balance the trunk above them, adduction and abduction are masked by pelvic tilting and lumbar scoliosis. In a similar way flexion and extension are masked by antero-posterior rotation of the pelvis with lordosis (lumbar extension) to mask hip flexion and relative kyphosis (lumbar flexion) to mask hip extension. Pelvic tilting with an adducted hip causes the affected limb to appear

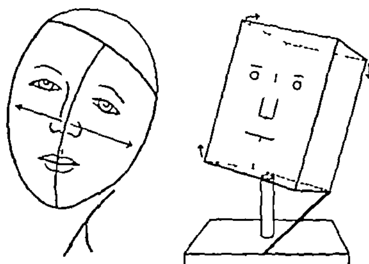


FIG. 125. *Aspects of Deformity—Torticollis (b).* Diagrammatic out lines of the head. The first shows the facial asymmetry due to cranial scoliosis. The second explains the complex action of the *sterno-mastoid* in producing lateral flexion and torsion, an action with which the opposite *splenius capitis* is synergic.

short while abduction causes apparent lengthening. Actual shortening of the limb in disorders of the hip joint always signifies structural shortening as the result of disease, malformation or injury. Structural deformity of the constituents of the hip may not be clearly seen though often it may be deduced from clinical appearances. In morbid anatomy and radiology the terms *coxa vara* and *coxa valga* are used to describe alterations in the angle of the axis of the femoral head to the femoral shaft. Normally in childhood development, the relative valgoid angle of infancy is reduced by muscular action and weight bearing to a relative varus. Abnormal angles in either direction are referred to respectively as coxa vara or coxa valga. In a special type of coxa vara, that seen at puberty or early adolescence and due to epiphyseal displacement, the deformity is by no means a simple varus. The femoral head rotates medially and backwards (valgoid and flexed) in relation to the innominate bone. In front of the head the femoral neck is rotated externally or everted (as well as being varoid) in relation to the femoral head.

Valgus (knock-knee) and varus (bow leg) deformities are frequently seen as the result of structural anomalies of the growing ends of the tibia and femur and these deformities may also result from injuries to the condyles of either bone.

In the foot special terms may be combined with varus and valgus to denote other peculiarities. Abnormal dorsiflexion and plantar flexion are described as calcaneus and equinus deformities. In *equinus* the foot is lowered in equine fashion so that the os calcis is off the ground. In *calcaneus* the reverse position of dorsiflexion causes the heel



FIG. 126 *Aspects of Deformity—Torticollis* ( ). Torticollis may result from muscle spasm or from subluxation. Here in one case it is due to a burn contracture and in the other to a chondromatous tumour of the cervical laminae

to be the lowest part of the foot in weight bearing. *Cavus* is used for the structurally abnormally high-arched foot associated with clawing of the toes *planus* for the structurally depressed arch *valgus* for eversion of the heel and abduction of the mid tarsals. Such deformities of the feet are seldom simple therefore it is often found that compound terms are necessary to describe them e.g. *equino-[illegible]-calcaneo-valgus cavo-varus* etc. The commonest fo[illegible] congenital club foot which [illegible] deformity of equino-varus in extreme cases ma[illegible] [illegible]arked that the head of [illegible] at the outer side comes into contact with the [illegible] weight bearing. Th[illegible] [illegible]ty by long custom has had attached to it the p[illegible] [illegible]s By bad usage this [illegible] been used as a generic title for all foot deform[illegible]

Pri[illegible] [illegible]ities in Relation [illegible]ry Effects

Many primary de[illegible] [illegible]uce compensat[illegible] [illegible]ments in [illegible] of the body which are equall[illegible] [illegible] as secondary [illegible] [illegible]nd the [illegible] ability We have mentioned the [illegible] [illegible]eral diseas[illegible] [illegible] specia[illegible] [illegible]d with

the interelation of parts of the body in posture and gait Torticollis (wry neck) is of particular interest As a purely postural deformity it may be secondary to an error of refraction and therefore related to variations in the reflex mechanisms of the oculo-cervical complex through the medullary and basal ganglia. It may be secondary to inflammatory disease in the soft tissues of the neck (e.g. lymphadenitis), or to acute infective arthritis in a cervical intervertebral joint and even become fixed by subluxation. As a secondary effect it may take part in the deformity of scoliosis arising lower in the spine and also as a compensatory effect of paralytic lesions of the shoulder girdle So-called postural scoliosis is a secondary deformity seen in any circumstance which results in true or apparent inequality in length of the lower extremities. In an individual with flexion contracture of the knee joint of long duration a secondary flexion contracture of the hip joint is not infrequently found and vice versa.

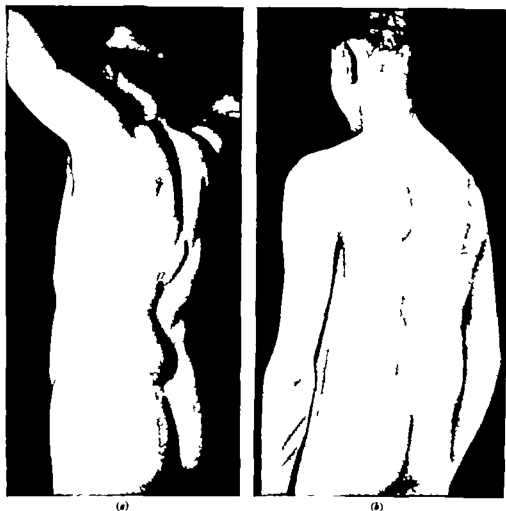
Inequality of Limb Length

True Shortening Congenital malformations of the limb may cause defects which range from minor but proportionate aplasia of the whole limb to gross aplasia which on the one hand will give rise to what are incorrectly called congenital amputations (at the end of which almost always are to be seen elements of digital buds) or may result in limbs which are peripherally normal but are short because of aplasia of for example, the whole femur or of both forearm bones and the humerus (phocomelia) Lesser degrees of shortening often associated with other elements of deformity are found in certain cases of dyschondroplasia. Deficiency of limb growth may be found in traumatic lesions of the growing ends and metaphyses of long bones and as a complication of prolonged immobilization of the knee in the treatment of tuberculosis of the hip joint. The stimulus to growth is related to muscular activity and vascular supply thus shortening may be due to defective growth in paralytic lesions.

True Lengthening. This may be the result of distraction in the treatment of fractures, but is usually a sign of hyperæmia, not infrequently associated with chronic osteomyelitis and even tuberculosis in the neighbourhood of the major growing metaphyses Congenital arterio-venous aneurysm or hæmangioma is an occasional cause

Apparent Shortening or Lengthening. In the lower extremity any circumstance causing lateral tilting of the pelvis by elevating one side or depressing the other will give the appearance of shortening of the elevated limb standing on the toes of one foot with the knee straight is the simplest way of normally producing this effect and a fixed equinus deformity of the foot will give precisely the same result. Abduction or adduction deformity or contracture of a hip joint, when the individual stands will be compensated for by downward and upward tilting respectively of the affected sides of the pelvis and so apparent lengthening or shortening. Tilting of the pelvis may also be brought about by contractures of the spinal and lateral abdominal muscles following paralytic lesions.

Variations in Size. This may be evidence of abnormality of the most various types quite apart from the circumferential associations of shortening or lengthening of a limb for example local developmental anomalies of the skeleton especially those of the dysplasic type neoplasms both innocent and malignant infective processes and other forms of osteitis and traumatic lesions. Swellings of the joints are often of characteristic shape following the outline of synovial reflections. Muscular atrophy is the commonest defect of soft tissue conformation and is of rapid onset as an active reflex phenomenon



(a) (b)

FIG. 128 *Aspects of Spinal Deformity* (*a*) A large abscess to the left of the lumbo-sacral joint with a *kyphosis* in the lower dorsal spine due to tuberculosis. (*b*) *Lordosis* at the dorso-lumbar junction with lumbo-sacral *kyphosis* d o severe spondylolisthesis.

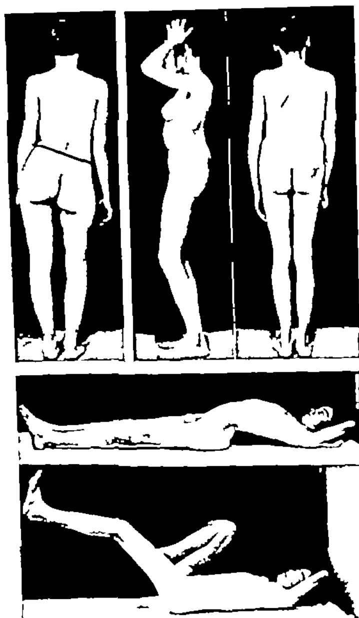


FIG 129 *Aspects of Deformity—Pelvis and Spine* (1) Lateral tilt due to fixed adduction of the left hip causes scoliosis and apparent lengthening of the right lower extremity (2 & 3) Backward tilting due to spondylolisthesis (apart from the deformities noted in Fig 128b) causes apparent fixed flexion of the hips and true flexion of the knees. (4 & 5) Forward tilting of the pelvis due to flexion deformity of the left hip causes severe lumbar lordosis (Thomas's sign).



(*a*) (*b*)

FIG. 128. *Aspects of Spinal Deformity.* (*a*) A large abscess to the left of the lumbo-sacral joint with a *kyphos* in the lower dorsal spine due to tuberculosis. (*b*) *Lordosis* at the dorso-lumbar junction with a *lumbo-sacral kyphosis* due to severe spondylolisthesis.

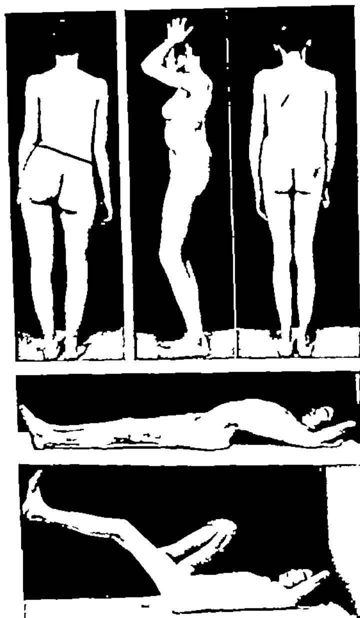
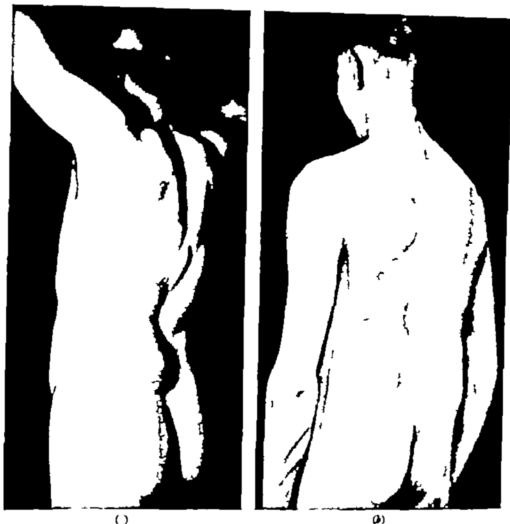


FIG. 129 *Aspects of Deformity—Pelvis and Spine* (1) Lateral tilt due to fixed adduction of the left hip causes scoliosis and apparent lengthening of the right lower extremity (2 & 3) Backward tilting due to spondylolisthesis (apart from the deformities noted in Fig. 128b) causes apparent fixed flexion of the hips and true flexion of the knees (4 & 5) Forward tilting of the pelvis due to flexion deformity of the left hip causes severe lumbar lordosis (Thomas's sign)



( ) (b)

FIG. 128. *Aspects of Spinal Deformity* (*a*) A large abscess to the left of the lumbo-sacral joint with a *kyphos* in the lower dorsal spine due to tuberculosis. (*b*) *Lordosis* at the dorso-lumbar junction with a lumbo-sacral *kyphosis* due to severe spondylolisthesis.

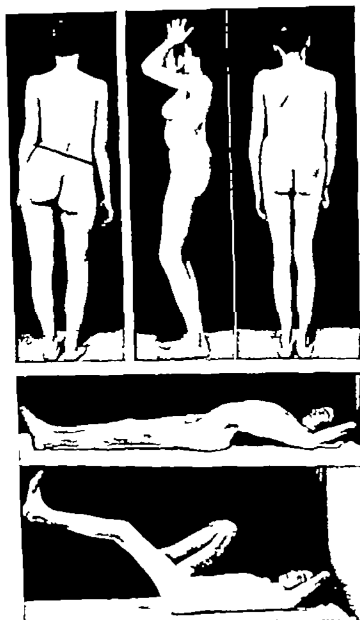


FIG. 129 *Aspects of Deformity—Pelvis and Spine* (1) Lateral tilt due to fixed adduction of the left hip causes scoliosis and apparent lengthening of the right lower extremity (2 & 3) Backward tilting due to spondylolisthesis (apart from the deformities noted in Fig. 128b) causes apparent fixed flexion of the hips and true flexion of the knees. (4 & 5) Forward tilting of the pelvis due to flexion deformity of the left hip causes severe lumbar lordosis (Thomas sign)

FIG 130. *Aspects of Deformity—Influence of Visceral Disease* Left peri-nephric abscess with lumbar rigidity and scoliosis and with hip flexion due to psoas spasm.

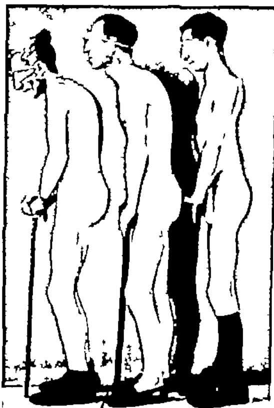


FIG 131 *Aspects of Deformity—Progression.* Three patients illustrating postural deterioration associated with the rapidity of ankylosing spondylitis.

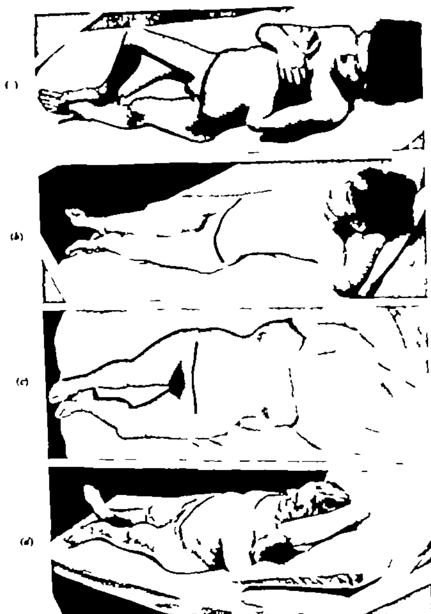
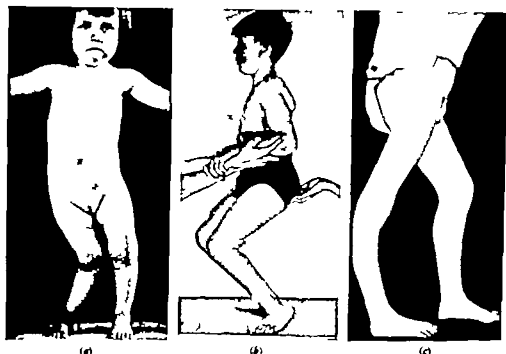


FIG. 132. *Aspects of Deformity—The Hip.*

(a) Early active tuberculosis of the left hip—splintage by the opposite limb
(b) Acute adolescent coxa vara—eversion and shortening.
(c) Acute septic arthritis with abdustion and lateral rotation left hip.
(d) Fracture of neck of left femur

the character and distribution of the mixed motor and sensory paralysis. Lesions of motor nerve endings in muscle are of general type and are usually considered within the group of muscular dystrophies or myopathies some of which are now being recognized as myositic in origin.

Amongst the direct lesions of muscle resulting in local weakness are the various forms of rupture of a muscle itself or of its tendinous portions, e.g. *rupture of the biceps*



(*a*) (*b*) (*c*)

FIG. 133 *Aspects of Deformity—The Knee*

(*a*) Genu valgum (R) and genu varum (L) due to rickets.
(*b*) Flexion deformities in cerebral palsy (spasticity).
(*c*) Genu recurvatum (R) in anterior poliomyelitis.

brachii or of the rotator cuff at the shoulder joint, avulsion of the biceps insertion to the radius, of the extensor attachments to a distal phalanx, rupture of the extensor mechanism of the knee or of the tendo achilles.

Upper motor neurone lesions are not notable for the element of weakness but rather for imperfections of control due to spasticity rigidity athetosis, ataxia or tremor *Methods for the grading of muscular power are dealt with in the section upon* Anterior Poliomyelitis.

Instability is a symptom mostly related to the use of the lower extremity It may be merely a sign of weakness. In other words a paralytic muscle may give unstable *control* of a limb as is well seen if the quadriceps femoris muscle is out of action. Even without paralysis the inhibitory atrophy of this muscle in certain lesions of the knee joint may give a marked sense of insecurity Characteristically such weakness is more apparent when walking down sloping surfaces than on level ground for in the latter very little muscular



FIG. 134 *Aspects of Deformity—The Foot*

(*a*) Talipes equino-varus—severe untreated congenital.
(*b*) Talipes calcaneus—poliomyelitic.
(*c*) Pes cavus—paralytic due to spinal cord tumour. Note skin pressure changes, clawing to toes and tilting of heel.

power is exerted by the quadriceps in extending the knee. *Any other circumstance limiting the capacity of the lower extremity to assume the normal posture required for propulsion will lead to instability* For example, stability requires a perfect fulcrum at the hip joint with no structural limitation of abduction.

Instability therefore implies imperfect articular structure for weight bearing, as well as abnormal mobility and muscular control Amongst the causes are dislocations, *subluxations, joint derangement by loose bodies, lax or torn ligaments, and poor muscular control.*

RADIOLOGY

It is a common mistake to regard radiological appearances as being as significant as those of a histological section, forgetting that radiographs are merely the fixed shadows (*skiagrams*) of opaque structures. *The abnormalities of translucency and the variations of architectural form and density these are merely suggestive of a pathologic process* and, however strong the suggestion may be, the appearances rarely indicate absolutely its nature. Taken out of the context of clinical information, variations can only be interpreted on the basis of probabilities. In the pathological lesions of bone the same radiographic appearances may be due to greatly different causes and the same cause may result in different radiographic pictures

For increased and diminished density of bony shadows the terms *sclerosis* and *decalcification* are used. These terms are misleading for both can be merely relative one to another Each term also is often inaccurate for the appearance of "hardening" of bone which sclerosis means, may not be hardening nor indeed a bony change at all. Increased density of radiographic shadow apart from technical causes may be purely relative to neighbouring lessened density In "decalcification" calcium is not removed from bone except when bone is destroyed or eroded What we mean by decalcification is usually de-ossification or removal of bone substance with thinning out of cortices and of the cancellous framework, in other words, *osteoporosis* To these phenomena the terms *apposition* and *resorption* are applied in pathology These are the constant activities of living bone and normally vary according to the demands of function and the needs of growth. In pathological processes one or other becomes abnormally dominant, and the extent and character of this gives rise to the radiographic appearances which have their suggestive pathological counterparts.

Radiology must therefore be directed to the synthesis of the clinical observations of abnormality in individual physical development, and in the disorders of disease or injury with the presumption of their pathological nature Such *clinical radiology* must be fully within the diagnostic competence of the orthopaedic surgeon

In the interpretation of radiographs, as in any visual phenomenon, there must be appreciation of the variations of apparent structure according to the position of the source of light (X-ray tube) and the position of the observer (photographic film) and the distance of each from the other (standard distances are 30 in. but for certain purposes teleoradiography is used, e.g. the cervical spine at 48 in. or 72 in.) Again there is a wide range of variation in normal and abnormal film densities according to intensity and character of X-radiation (e.g. with soft ray of low voltage or hard penetrating ray of high voltage) also depending upon times of exposure and of development of the photographic silver emulsion. The tissues of the body vary in their density or opacity to irradiation

and consequently of the intensity of the shadow which they cast upon photographic media In most radiographs the soft tissues are made visible more or less clearly and the observation of their shadows may be of considerable diagnostic importance, as for example in the demonstration of abscesses in tuberculosis of the spine or of distension of synovial cavities and the swellings around joints, and of the shape of soft tissue tumours. Such shadows may be accentuated by the employment of special low voltage radiation techniques.

For the correct interpretation it is necessary to have radiographs taken from at least two points of view most frequently by antero-posterior projection of radiation of film material together with an exposure from the lateral or medial aspect of the part being studied. There are many occasions, however when valuable information may be added by the provision of oblique, axial and tangential views.

Tomography A method of obtaining sectional radiographs of deeply placed tissues which are brought into focus upon the sensitive film by blurring of the detail of superficial structures is of particular value in the study of the dorsal spine, and of its internal structure by lateral radiographs free of the confusing shadows of ribs and scapulæ. *Opaque Radiography* also has some useful purposes. Heavy iodized oil may be injected into sinus tracks so that radiographs may demonstrate their ramifications Special preparations of similar character are used within the spinal canal for the study of lesions encroaching upon the subarachnoid space (*myelography*) as for example intrathecal or extra-dural tumours, intervertebral disc protrusions or compressive conditions arising from the vertebræ, e.g. Pott s Paraplegia. For many of these conditions 2–3 c.c. of the material is injected into the theca through a normal lumbar puncture and the patient is tilted head downwards on the radiography table so that under fluoroscopic control the course taken may be studied and photographed. Where there is presumed to be an intra-spinal block, then the radiographic studies may more satisfactorily be performed after injection of the material into the cisterna magna. The material is then followed downwards the patient being tilted with his head up. For *Arthrography* an opaque material is used which is non-irritant and is readily absorbed from synovial cavities. Thirty-five per cent diodone in its many forms, such as are used for intravenous pyelography is satisfactory It is useful in the study of certain joint derangements and arthritic conditions and has been of particular interest in explaining the anatomical peculiarities of congenital dislocation of the hip. As a method of study and research such arthrographies have been important, but they play a small part in routine clinical work. Another method employed has been pneumo-arthrography in which air or oxygen is used so that contrast is obtained by this more transparent medium as compared with the opaque character of the iodine derivatives. Air arthrography would appear to have the possible special risk of air embolism. A special radiographic technique of interest in orthopedics is that designated by American workers as *scanography* It is used in the accurate measurement of comparative limb lengths in cases of inequality A narrow beam of X-radiation is passed through a transverse slit in a filter in front of the X-ray tube and the latter is moved lengthwise over the course of the limb, behind which is placed a length of X-ray film or overlapping sheets if the length of the limb to be measured is too large for one film. Only X rays at right angles to the film affect it. Although there will be lateral enlargment of the shadow length will be accurately measurable.

The quick and accurate interpretation of radiographs is to be achieved by long

practice. Observation is not only a matter of seeing it depends upon perception. The practitioner must first train himself to know the normal In the examination of an X-ray film a beginner tends to concentrate as he does with a portrait, upon the central area or point of focal interest. It is as well to get the habit of looking at the periphery then at the centre and perhaps even to go back to the periphery A tuberculous lesion of the twelfth dorsal vertebra may thus be found in a film taken in the course of barium investigation of the abdominal viscera. Do not restrict perceptive powers to the anatomical region or system with which one is particularly concerned.

SOME GENERAL CONSIDERATIONS OF BONE PATHOLOGY*

Before discussing specific pathological changes in bone, which will be mentioned when the separate conditions are dealt with it may be convenient to consider here a few general points, since bone differs in some ways from other connective tissues. Collagen is extensively present in connective tissues but bone is unique in that the collagen is embedded in a special protein material (cement) and is impregnated with bone salt to give it rigidity Another special point is that bone is laid down at different periods in the life of the individual, before and after birth, and that far from being a lifeless inert structure, it is constantly changing. From studies made with calcium salts labelled with a radio-active isotype, it has been shown that after intravenous injection, 86 per cent of the calcium will be taken up by the bones in 100 minutes. Similar studies have shown that there is a constant interchange between the calcium in the bones and that in the tissue fluids and that the entire calcium in the bones can be replaced in 200 days. During normal adult life a balance is struck between calcium deposition and absorption in childhood and adolescence when bone formation is rapid, deposition exceeds absorption, while in later life absorption tends to be greater than deposition and rarefaction of bone may occur

Bone is laid down by special connective tissue cells—osteoblasts—either directly from fibrous tissue, as in periosteal bone formation or more usually from cartilage. When the bone has been formed and calcified the osteoblasts become bone cells and thereafter can take no part in bone formation. Absorption of bone takes place entirely by the action of specialized multi nucleated cells, the osteoclasts. These cells, by means of a special enzyme contained in their substance, are able to dissolve away the portion of bone with which they come into contact. The indentations (Howship's lacunae) on the surface of the bone are a certain indication of osteoclastic activity It is generally accepted that bone absorption, whether physiological or pathological, takes place in no other way than by osteoclastic activity and that so-called halisteresis—the abstraction of calcium from bone without removal of the bone itself—does not occur

S. L. Baker (1950) summarizes his views on the mechanism of bone deposition and absorption as follows (a) Bone formation takes place in two stages, (1) the formation of an organic matrix by the osteoblasts, (2) the conversion of this osteoblastic tissue into bone by the deposition of calcium salts. (b) Bone is removed by a one-stage process in which osteoclasts remove the matrix and the bone salts together

Since bone contains about 97 per cent of the calcium in the body its pathology must to some extent be bound up with calcium and phosphate metabolism and with

* We are indebted to Dr Stewart Smith, Area Pathologist, Exeter for this contribution.

phosphatase activity The normal serum calcium level is 9–11 mg./100 ml about one half of this amount is diffusible, ionized and physiologically active while the other half is bound to protein and is therefore non-diffusible The non-diffusible calcium is chiefly bound with the serum albumen and any conditions giving high serum protein levels will be likely to increase the serum calcium In nephrosis where serum albumen is reduced the calcium concentration will also be lowered. It is therefore essential to estimate the serum proteins before assessing the importance of a raised serum calcium level This level remains remarkably steady and is not influenced by local bone absorption In fact bone can undergo absorption in order to maintain it. Bone salt is largely calcium phosphate with a smaller amount of calcium carbonate and usually the calcium phosphorus ratio is as 2:1 It is under close control of the parathyroid glands, and parathyroid tumour or occasionally parathyroid hyperplasia will lead to the mobilization of calcium from bone, possibly by direct osteoclastic stimulation. The result will be a high serum calcium, a low serum phosphate and either generalized or localized rarefaction of the skeleton (osteitis fibrosa)

Vitamin D if given in high dosage, increases the absorption of both calcium and phosphorus from the intestine and may lead to high blood levels. In Paget's disease, in which bone absorption and bone deposition are taking place at the same time, these opposing processes may well be balanced and if so the serum calcium level will be normal. Some patients with hyperthyroidism may also show excessive osteoclastic activity and calcium excretion but here the serum calcium level is not usually raised.

Phosphorus metabolism is so bound up with calcium metabolism as far as bone is concerned that the two should be considered together The serum inorganic phosphate (normal level 3–4 mg./100 ml.) varies inversely with the serum calcium so that the product of the two is about 40 in adults and up to 60 in children, when each is expressed in mg. per cent. There does not appear to be an adequate explanation for this ratio

The purpose of phosphatase is to produce inorganic phosphate from monophosphoric esters. Alkaline phosphatase, so called because it is active in an alkaline medium, is produced both by proliferating epiphyseal and metaphyseal cartilage cells and by osteoblasts It increases the local concentration of calcium phosphate beyond the saturation point and so the salt is precipitated into the newly formed osteoid tissue. The normal serum level of 3·0–13·0 King Armstrong units/100 ml. will be increased whenever active bone formation is proceeding. Apart from obstruction to the intra or extra-hepatic ducts, when the enzyme may be returned to the blood stream instead of being excreted in the bile, an increased serum alkaline phosphatase is found in patients with active rickets, Paget's disease, hyperparathyroidism or with secondary deposits in bone of such tumours as lead to new bone formation. Osteolytic metastases and conditions such as myeloma give normal results.

Acid phosphatase acts in a medium of pH. 5·5 and after puberty is formed chiefly by the prostate. The normal values are 0–2·0 King Armstrong units/100 ml Various methods have been used to distinguish acid phosphatase of prostatic origin from that produced elsewhere and it is now usual to report as prostatic phosphatase that which is not inhibited by formaldehyde, the so-called formal-stable phosphatase This fraction also has a normal level of 0–2 King-Armstrong units/100 ml. About 80 per cent of cases of carcinoma of the prostate with bone metastases will give levels of over 5 King-Armstrong units/100 ml. and figures as high as 60 may be reached some 30 per cent of

cases of prostatic cancer without metastases may show some increase. The acid phosphatase level should fall steadily to normal under adequate œstrogen treatment an increase in the level in a patient under treatment is usually an indication of a relapse.

CLINICAL FINDINGS IN BLOOD AND URINE IN SOME DISORDERS OF BONE

Condition	Serum Calcium	Serum Phosphate	Serum Alkaline Phosphatase	Serum Acid Phosphatase	Calcium in Urine
Rickets	Usually lowered	Usually lowered	Usually raised	Normal	
Osteomalacia	Low	Usually lowered	Usually raised	Normal	
Renal osteodystrophies	Low	High	Normal	Normal	
Senile osteoporosis	Normal	Normal	Normal or slightly raised	Normal	Increased
Hyperparathyroidism	High	Low	High	Normal	Increased
Thyrotoxicosis	Normal	Normal	May be slightly raised	Normal	Increased
Paget's disease	Normal	Normal	Raised	Normal	
Myelomatosis	May be slightly raised	Normal or slightly raised	Normal	Normal	
Carcinoma of prostate with metastases	Normal	Normal	Raised	Raised	
Primary tumour in bone	Normal	Normal	May be slightly raised	Normal	
Secondary tumour in bone	Normal	Normal	May be slightly raised	Normal	

Examination of the serum proteins may give valuable information in three different groups of orthopædic conditions (1) where there is an alteration of the serum calcium level and it is essential to know how much of the calcium present is protein bound, (2) in conditions where there may be serious protein loss associated with chronic discharges or particularly with burns, and (3) when protein of a special type may be present. Myelomatosis and sarcoid deposits in bone are examples of this latter group Electrophoresis will enable the precise increased globulin fraction to be identified.

It may be appropriate to consider here one or two terms used in connection with the

pathology of the bone and to describe ways in which bone may react differently from other connective tissues.

Osteoporosis is a diminution in density or a rarefaction of bone. This condition may result (*a*) from defective deposition of bone salt, as best seen in rickets and osteomalacia, or (*b*) from excessive absorption of bone by osteoclasts as in Paget's disease, osteolytic neoplasms and particularly in hyperparathyroidism. A diminution in the radiological density will result equally from either cause.

Necrosis of bone is due eventually to loss of blood supply. When examined microscopically it will be seen that the nuclei have disappeared from the dead bone but because of its rigid structure no gross change may be obvious for a considerable time. Dead bone such as is used in bone grafts, can be revascularized and although in most cases it will eventually be removed by osteoclastic activity it can for a long period act as a scaffold around which new living bone can be laid down. When the surrounding blood supply is deficient, dead bone, whether it has formed owing to infection or has been inserted as a graft, will fail to be revascularized and will not be dealt with adequately by osteoclasts; ultimately it will be rejected and become a sequestrum.

Osteoid tissue is bone matrix without bone salt. Owing to the absence of calcium it is not radio-opaque. As a pathological process the extensive laying down of osteoid tissue is perhaps best seen in Paget's disease where the soft poorly calcified bone can often be cut with a knife.

Reference

Baker, S. L. (1950) Text Book of X-ray Diagnosis (Second Edition). *H. K. Lewis*, London, p. 81

TREATMENT

Introduction. Treatment is dependent upon accurate diagnosis. Rest as a supportive measure must be applied physiologically with appropriate activity. Splintage plays its part in this together with physical therapy having particular reference to the re-education of muscular control and joint movement. The use of drugs plays a relatively small part in a regime which is primarily concerned with reinforcing the natural processes of growth and repair. Manipulative non-operative surgery has a wide field of usefulness in orthopædics. In the mind of the practitioner all branches of therapy must have regard for the social background of the patient and his psychological well being. Rehabilitation to a normal economic and social life may require special attention to vocational training.

Operative surgery is of urgent character in the treatment of open wounds and fractures. Of relative immediacy may be the operative treatment of other fractures and soft tissue lesions. There is, however, a wide field of elective surgery which may require careful planning within a campaign of treatment that involves many other therapeutic techniques. This is seen particularly in the problems of residual paralysis following anterior poliomyelitis where the plan of approach in a child may envisage work ten or more years ahead.

Rest as a Part of Treatment

Historically for at least a century there has been a conflict between those who advocate rest as a dominant principle of treatment and those who take a more active attitude. Today there should be less reason for argument because of the great advances in the

reverse i.e. active lengthening against load. To these three actions isometric and isotonic contraction and isotonic lengthening there are complementary phases of relaxation which are performed synchronously by antagonist muscles. The co-ordination of these complementary phases is dependent upon reflexes of both peripheral (proprioceptive) and central origin.

In the active central control of muscles it must be recognized that the consciousness is not concerned with individual muscles rather is it with actions which usually are expressions of the functions of groups of muscles. For this reason anatomical teaching of muscular functions can be misleading. Not only because of the different phases of muscular action above mentioned but particularly for the idea enunciated by von Baeyer In the normal activity of the body he emphasized the importance of the type of activity seen in what he called the "closed kinetic chain" in which muscles act from points of peripheral fixation or where peripheral resistance is greater than that at the centre of the body circumstances well seen in the leverage between hand and foot with the intermediary of the earth or external objects. These are the circumstances of every day working conditions and involve not only a reversal of muscular action so that the central end is the moving part but also results in paradoxical muscular effects such as may cause deformity

SPLINTS AND APPLIANCES

The word splint has come to signify immobilization, but this may be misleading. Originally the word was used in connection with ancient armour where "splints" were the sections provided around joints which permitted movement while providing protection. In mechanical engineering a spline is a device for preventing movement in one direction while permitting it in another In surgery splints serve a variety of functions including the following

(1) Immobilization or the limitation of movement.

(2) Support in opposition to the influence of gravity

(3) Correction of deformity

(4) Mobilization of joints.

(5) Substitution for or assistance of defective muscles.

Appliances must be designed to fulfil these functions with maximum comfort, convenience and efficiency This involves lightness and accessibility smoothness in anatomical fit, adequate strength, simplicity of design and economical and speedy manufacture. The wedding of mechanical efficiency with comfort in use is often difficult. The Thomas bed-knee splint, in spite of later useful modifications, still remains as used by its inventor a supreme example of such a marriage. In design and manufacture, good splints need the co-operation of the surgeon with the craftsman.

Plaster of Paris. For most short term purposes plaster of Paris has come to hold an important place which, so far the invention of new synthetic "plastics" has not been able seriously to challenge It is used as a powder which in composition is amorphous anhydrous calcium sulphate obtained by baking gypsum in a kiln. Bandages of book muslin or crinoline are impregnated with this powder which, when immersed, takes up water some of which combines with the plaster to form crystalline hydrated calcium sulphate, and the excess of water is removed later by evaporation. In the process of

setting or hardening, some further heat is given off and a certain amount of expansion takes place, and it is easy for distortion to occur if plaster splints are not dried evenly throughout. For this reason a free circulation of dry warm air is advisable, and during the process of setting and drying, splints made of plaster are particularly susceptible to mechanical stress and therefore must be evenly supported throughout.

A certain amount of controversy has existed as to the relative merits of padded or unpadded plaster splints. There need be little question, except on the ground of economy that the advantages are greater in using a thin, even lining because of greater comfort to the patient. The idea of padding came into disrepute because such was often bulky and uneven and prevented accurate application to the contours of the part being treated. Plaster of Paris is a versatile material. Apart from being used circumferentially as a bandage, it may be made up in "slabs" of 8–16 thickness of impregnated muslin in lengths of 15 in. or 20 in., which for immersion are folded or lightly rolled. In either case the material is immersed in water until all air is expelled and the excess of water is pressed out gently before the material is applied to the limb The opened out wet slabs may be folded or rolled across the width and used as re inforcing bars or ridges on the exterior of plaster splints at the site of special vulnerability for example the front of the hip joint. Slab plasters are very convenient also as moulds applied to one aspect of a limb, and bandaged thus so as later to form a readily removable splint for daily treatment. Plaster may be used in the form of a cream prepared by sprinkling 2 parts of plaster quickly into one part of warm water In this state it may be soaked up into muslin sheets and thus applied to the body as for the preparation of plaster beds (Nissen). Such a cream is also used in the preparation of casts of limbs as is necessary for the manufacture of certain semi-permanent appliances made of leather or synthetic plastics. In applying the plaster in any form to a limb it is necessary during the process to mould the plaster while it is still soft, to the contours of the limb, and in so doing to press out any air spaces which may be otherwise incorporated Such manual moulding helps to give greater compactness and strength with the minimum of material, and by following the contours of the limb accurately minimizes the risk of pressure sores within. While plaster is being applied and until setting is well-advanced, the part must be held continuously in the desired position, for if movement of any area is permitted, cracking or infolding may occur with the consequent need for reinforcing with unnecessary material, or on the other hand, the formation of ridges internally which cause pressure points. Particular care must be taken to avoid fingertip pressure for the same reason. While for hospital purposes it is necessary to have special tables and appliances to hold patients, plaster technique offers great scope for efficient improvisation as has been admirably shown by Quigly The use of simple calico slings and everyday objects to suspend them, may permit the application of as perfect a splint as with the use of elaborate machinery

Plaster splints may be used for the purpose of obtaining slow correction of deformities by the process of cutting transversely on the concave side and inserting blocks of increasing thickness between the cut edges, at daily or more or less frequent intervals according to circumstances thus the deformity if due to soft tissue contractures, may gradually be overcome. This principle was applied first by Lovatt in the correction of flexion deformities of the knee joint. A similar method in the treatment of club foot has been advocated by Kite with excellent results In this however a section of plaster is removed and the gap is closed in the direction in which correction is desired. Various mechanical

FIG. 135. *Improvisation in Plaster of Paris Techniques* as employed for a Risser plaster for scoliosis which later will be divided into two sections for turn-buckle correction.



FIG. 136. *Long Leg Guarding Plaster* for acute lesions of the knee—split for exercise

FIG. 137 *Wedging Corrective Plaster* for flexion deformity of the knee.

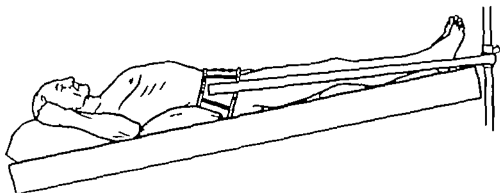


FIG. 138. *Pelvic Traction* upon an inclined bed in the treatment of acute lesions of the lumbar spine and sciatica

contrivances can be used in plasters which have been completely divided into two portions for the slow correction of deformity *The turnbuckle plaster with metallic hinges* has a sphere of usefulness particularly after neuro-synthesis as, for example the sciatic nerve

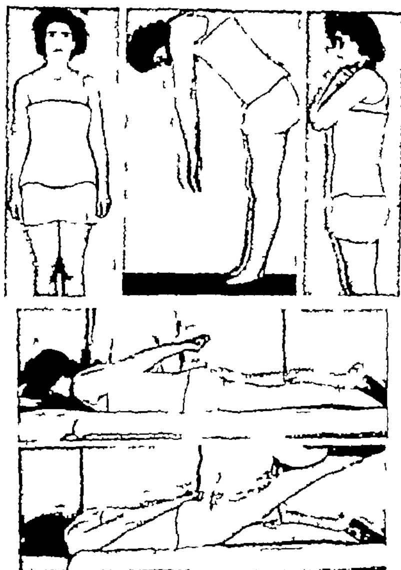


FIG 139 *Plaster Jacket and Remedial Exercises* in the convalescent phase of treatment for acute lumbo-sacral lesions.

where extension of the knee requires careful control or in the elbow after operations upon the median, ulnar or radial nerves. The same principle is used in the Risser jacket for the correction of structural scoliosis preparatory to operative fusion.

A somewhat different use of plaster in the correction of deformity is that introduced by Macrae Aitken for the correction of equinus deformities of the foot due to a short

calf musculature. The use of a plaster applied in the best obtainable position to include the foot and knee joint is followed by removing the portion of plaster under the heel as far forward as the metatarsal heads, which are supported in the plaster and well padded. The patient by walking on the metatarsal heads pushes his body weight through the plaster in such a manner as slowly to correct the calf contracture. In certain cases, particularly in poliomyelitis, this very effective method avoids the necessity for tenotomy.

In plaster of Paris we have a material which provides an almost ideal method of providing support and immobilization. In use it provides scope for craftsmanship and

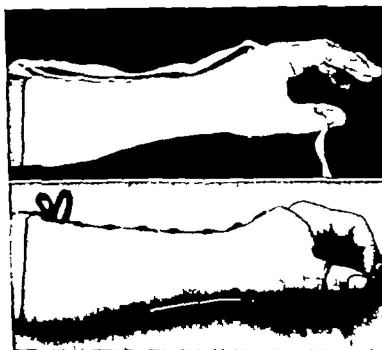


FIG. 140 *A Plaster Mould* as used in the preparation of a block leather or plastic splint.

ingenuity without skill it may be unnecessarily irksome to the patient and can even be dangerous. It has certain defects chiefly due to its slowness of setting and its tendency thus to suffer distortion in the process.

Moulded Appliances

Various alternatives have been tried, such as bandages made of fibre glass and acrylic resin, which have their own peculiar disadvantages of expense, the need to employ dangerous solvents and the tendency for the material to contract while hardening. Plastic acrylic sheets moulded under heat to the shape of the parts to be splinted have lately acquired a certain vogue. The advantage of all these materials is in their lightness and cleanliness but against this must be set their impervious nature and, for the acrylic moulds, that a cast of the limb must first be prepared from a plaster of Paris mould. The latter procedure must also be employed in the older method of blocking leather which

still has much to recommend it for certain types of appliance In this, well soaked leather is stretched and stitched on to a concrete or leaden cast of the limb. When dry it is removed by cutting down the stitching on one side then polished on the surface, lined with chamois, provided with lacing hooks or straps and reinforced where necessary with duralumin strips. The advantage of leather is in its lightness and porosity

A further type of plastic material, polythene, is used in a similar manner after heating, but by the interposition of a sheet of foam-like character made of the same material, the polythene can be moulded directly upon the patient.

Metal Appliances

These have a history almost as ancient as surgery itself—certainly as old as metal armour Like armour most old splints were hammered out of metal sheets moulded to the shape and surface of the limbs, and both types of appliance were probably fashioned by the same craftsmen.

The need for metal splints has been dominant in the lower extremity where rigid support has been necessary Modern ideas have evolved from nineteenth century experiment, notably with the work of Hugh Owen Thomas based upon his recognition of the need for appliances which would permit traction with physiological support of the soft tissues while controlling axial deviations. The outstanding example is the Thomas caliper splint which in its various forms for bed treatment or ambulant care remains a supreme example of simplicity with fitness for purpose" The principle of its construction offers great versatility for modification to particular uses. The natural stability of the lower extremity is greatest from side to side because of the collateral ligaments of the knee and ankle

The caliper side pieces of rigid iron or mild steel wire being applied on the medial and lateral sides of the limb are well placed for fixing slings or other devices for the control or encouragement of antero-posterior mobility Furthermore, the presence of a ring shaped junction between the two side pieces at the top offers the possibility of a bearing against the soft tissues beneath the tuberosity of the ischium and, with a transverse junction of the side pieces at the bottom, permits traction to be applied through extension straps adherent to the skin or through cords attached to skeletal transfixion pins. Every part of such an appliance has been modified by innumerable surgeons. Although there are today many Thomas splints so called, which H. O Thomas himself would have had difficulty in recognizing, yet the principle remains. It is used not only in the treatment of fractures particularly of the femur and in infective lesions of the knee joint but also for many other purposes for patients in bed, and it is used widely in the design of caliper appliances for the ambulant patient notably in the convalescent treatment of fractures and arthritic conditions, and for longer term use in certain cases of residual paralysis particularly poliomyelitic. Rarely however should either surgeon or patient allow himself to regard such an appliance as a necessary end in itself.

The use of the ring top for counter traction in the bed splint is also applied in the ambulant caliper for taking the weight of the body where it is necessary to relieve the lower limb of its supporting function. Where it is not necessary for the appliance to bear weight from the soft tissues beneath the tuberosity of the ischium the top of the caliper may be made of flat metal, covered with leather and shaped to the back of the thigh in the form of a half cuff completed by leather straps in front, or a leather thigh corset may

be fashioned In all such walking calipers some attachment to the shoe is necessary and most frequently this is to a tubular socket passed through or in front of the leather heel Further support or control of the limb is provided by leather slings in front and behind the splint In certain cases added rigidity may be given by the use of a shaped metal band between the side irons behind the calf

Such an appliance which holds the knee immobile should generally be applied so that this joint is not quite fully extended—particularly in children with paralytic lesions so as to avoid posterior capsular stretching and thus hyperextension. If limbs are of equal length it is usually necessary to add half an inch or so to the leather of the shoe on the normal side so that the inflexible caliper-held limb may easily clear the ground in walking.

For patients to whom the use of a caliper is a more permanent necessity it is in most cases desirable to cater for the possibility of knee flexion when sitting. Various types of knee joint caliper are available. Most of these are provided with some form of locking device, so that in the standing position the appliance is rigid in extension. In special circumstances appliances of the jointed type may have free movement of the knee with a limit to extension which may be so arranged by providing a posterior axis for the articulation that, in full extension, the appliance automatically remains stable by reason of the forward displacement of body weight in front of the axis of movement. In calipers for permanent use one may provide another range of movement at the ankle with a joint coinciding with the axis of the natural articulation.

Below Knee Appliances. The principle use for "short irons" is the control of side to side movement of the foot—particularly at the sub-talar or mid-tarsal joints. This usually is achieved with side irons joined above at the level of the tubercle of the tibia by a posterior half ring of flat metal with a leather cover and a leather buckle strap in front. At the lower ends the irons are bent at right angles to form spurs which fit into metal heel tubes as used for the long caliper This by itself gives a measure of control to inversion and eversion of the foot and such control may be re-inforced by T-straps which are stitched to the medial side of the shoe and buckle round the outside iron for eversion and to the lateral side of the shoe and round the inside iron for inversion. For a paralytic drop foot, toe raising springs may be attached to the upright irons by a V strap and to the front of the shoe by another similar strap stitched to each side of the sole or through a metal loop attached to the lacing holes of the front part of the shoe lacing. Alternatively the metal uprights may be jointed at the level of the ankle and the lower segment provided with a lever for the attachment of a spring to raise the foot. Lighter and mechanically more efficient toe raising devices are available made from lengths of spring wire which take the place of the side irons and are themselves coiled at the level of the ankle joint the whole appliance thus comprising a spring. This is one of a group of similar appliances which at Exeter have been designated as "Lively Splints."

The Jones Double Abduction Hip Frame. A special word should be given to the use of this appliance which, though based originally upon the Thomas spine and hip frame, was formerly used very extensively in the treatment of tuberculous disease of the spine and hip. The need for this appliance has now become greatly reduced. Nevertheless, it is useful in the treatment of some phases of acute infective lesions of the hip joint, the early active stages of osteochondritis of the femoral head, and as an appliance *for the* reduction of congenital dislocation of the hip joint. The appliance is in two *main forms*, one having adjustability of both hips to angles of extreme abduction another the

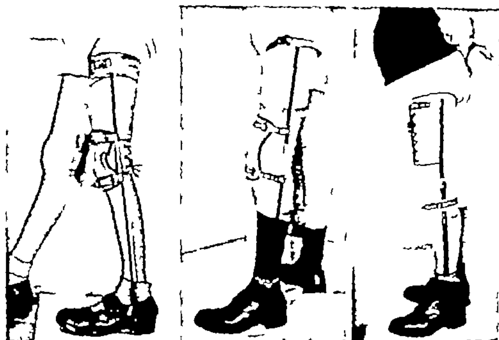


FIG. 141 *Three Types of Long Caliper Splint* (a) Cuff top. (b) Ring top (c) Corset top with locking knee hinges.

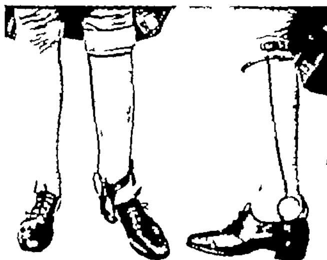


FIG. 142 *The Exeter Type of Lively Splint* here used for raising a paralytic dropped foot.

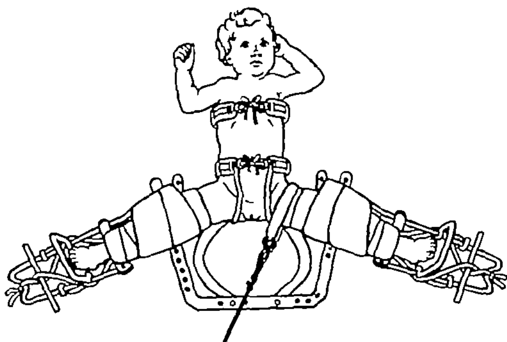


FIG. 143. *The Oxford Type of Double Abduction Hip Frame* as used for the reduction of a congenital dislocation of the left hip.

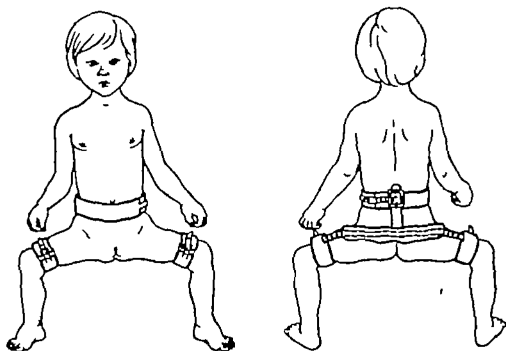


FIG. 144 The Denis Browne convalescent hip splint for congenital dislocation of the hip.

original form, having a fixed hip angle on one side and an abduction device for the opposite hip. Essentially the apparatus comprises a metal framework supporting the spine and both lower extremities, with the interposition of leather covered pads. To the trunk section are added transverse soft malleable metal bars which in some examples are hinged at the side. These bars placed at the level of the nipple line and the truss line permit control of the child's body at the same time providing opportunities for counter traction through straps attached to the back of the appliance, and passing forwards on each side of the perineum to be attached to the pelvic transverse bar. The limb sections of the appliance are in principle similar in construction to the Thomas bed-knee splint, in having lateral and medial irons joined at the bottom of the appliance below the foot, to which extensions from the lower extremity can be attached. These side supports do not provide slings as in the Thomas bed knee splint, but offer the possibility of controlling the rotational position of the limb by the attachment of immobilizing bandages. The double abduction frame has been specially developed at the Nuffield Orthopaedic Centre, Oxford, for the treatment of congenital dislocation of the hip in small babies.

Denis Browne Hip Splint. This may be used during treatment of congenital dislocation of the hip after reduction in such an appliance as is mentioned above, or when the hip has been reduced by other methods. This simple leather-covered metal strip is applied to the back of the fully abducted hips, and retained by leather straps around the lower ends of both thighs and a further strap attached around the waist of the infant. This splint allows a certain amount of lateral movement from the fully abducted position both inwards and outwards and maintains the thigh constantly in the coronal plane. It permits no forward flexion which according to Denis Browne is the position most likely to encourage re-dislocation.

Splints for the Upper Extremity. Apart from the forearm and hand there is very small scope for the use of external appliances. If control for the shoulder is required, it is preferable to use plaster splintage for it is very rarely possible to use a prefabricated metal appliance which will be both mechanically efficient and comfortable. For the elbow plaster also is preferable nevertheless, in the convalescent care of tuberculous disease of the elbow some form of moulded appliance of plastic material or leather may be required and it is prepared in the manner already described.

Splintage for the Hand. It is here that the use of mobile or "lively" splints has greatest scope.

In the physiological control of the hand it should be noted that the surgeon is dealing not with a single member but with a group of closely linked digits, and that the function of one hand is closely related with that of the other. Furthermore, it must be realized that the motor function of the hand depends very largely upon its sensory activity both superficial and deep. While, therefore, short term treatment by splintage can be adequately dealt with by plaster of Paris, in most cases, for anything but the shortest period of immobilization, appliances must be devised that have full regard for sensory function and mobility. A cock-up splint must be shaped so as to leave as much as possible of the palmar surface free. Appliances are adjusted to the concavity of the palmar surface so as to conform to the compound obliquity produced by the double angle of grip. The mobility of appliances for the hand is provided by spring construction and the principle should be that the axes of movement or the fulcra of levers conform as nearly as possible with the axes of limb movement. Spring action should never be stronger than is necessary

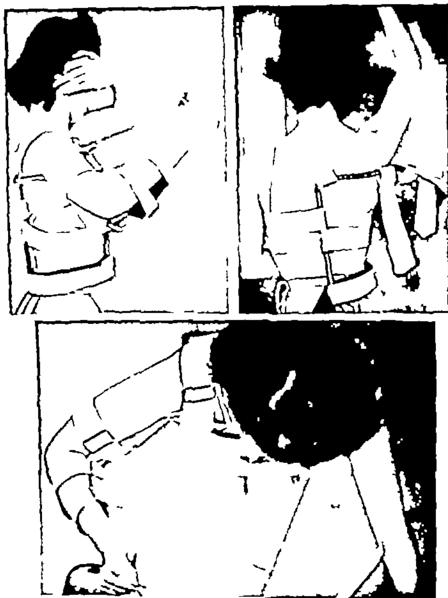
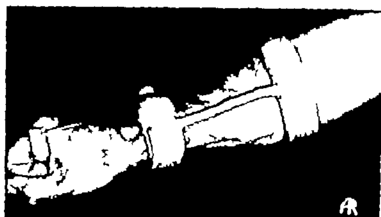


FIG. 145 The *Littler-Jones* (Oxford type) shoulder abduction frame.



(a)



(b)





(c)

FIG. 146. *Appliances for the Hand.* Cock-up splints which allow maximal palmar sensory function and are shaped with due regard to the double palmar obliquity

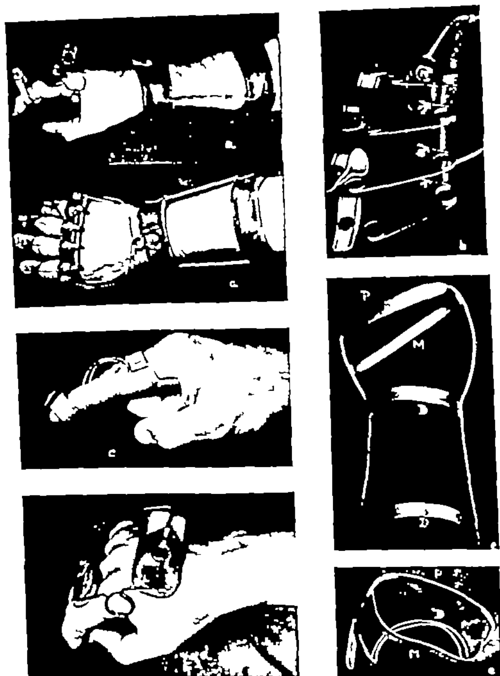


FIG. 147 *A Variety of Lively Splints.* (*a*) The completely flexible "Soter" hand splint. (*b*) Detail of method of attachment of springs to phalangeal bar and showing adaptability of lever length and multiple coiling. (*c*) The "Soter" finger splint. (*d*) The spring cage for intrinsic paralysis in which the framework comprises one continuous spring. (*e*) Two views of basic framework before padding *and before adding springs for finger extension this frame is used where more rigid control of the* wrist is necessary P = Phalangeal controlling bar for spring attachments. M = Oblique metacarpal palmar support. D = Dorsal bands for forearm.

to achieve a particular purpose. The physiological position of the hand joints should be retained by the appliance when the musculature is relaxed. For deformities of joints, as in arthritis or cicatricial contractures, lightness of spring action is very important so as to avoid painful stretching (and consequent reflex inhibition of muscular action), and so safeguard the circulatory condition of distal parts. Power that seems light for a normal hand may be too strong for the correction of deformity. The use of spring wire either as an integral part of the construction of a splint, or as an added feature, provides great adaptability to the particular needs of every joint. The spring in such an appliance acts as a motor by torque. Its helix is compressed by the weight of the limb and by the action of antagonist muscles. Relaxation of the latter causes the spring to act by the rebound from its torque. Length of spring arm provides leverage, and this is affected by the elasticity of the material. The strength of the spring is dependent upon the calibre of its wire, the size of the helical coils, and their number and length of wire (material being constant). The multiplication of coils increases elasticity and reduces power.

Using such mobile appliances one should remember that in the hand, function involves an orchestration of motor and sensory activities. Absence of, or defect in any of the instruments of this orchestra, produces imbalance or discord in the rest. Substitution for lost instruments may restore balance because of the harmonics of reflex activity induced by sensory stimuli especially those of proprioceptive nature. Such artificial balance may aid the restoration of natural balance if other circumstances permit it.

Spinal Splintage

Bed Appliances. For maximal fixation of the spine as, for example, in the treatment of tuberculous disease, the posterior plaster shell which may extend to the ankles is carefully moulded direct to the patient's skin as he lies on his face upon pillows. In this position the hip and knee joints are supported in slight flexion with an angle of 30 degrees between the limbs. In this plaster shell it is convenient to support the patient upon a Bradford frame made of 1 in. gas piping, stretched with sail cloth having a "nursing" gap about 9 to 12 inches wide situated under the buttocks and perineum.

For turning purposes a second Bradford frame is placed in front of the patient and held by straps which surround the two frames and the patient in the plaster shell between them.

By the attachment of extension pieces from the side of such a frame it is easy to sling the patient with counter balancing weights acting through pulley blocks and tackle, as described by Nangle, so as to facilitate changes of position and thus minimize the risks of decubitus, particularly those which encourage urinary stagnation and calculus formation.

Ambulatory Appliances. The efficiency of all such splints for immobilization is small. Their use is to provide some restriction of activity and some support for the spinal extensor muscles; they can provide very little support for the spine itself. In Great Britain two relatively simple appliances are commonly used. (*a*) The Jones support. Essentially this is a leather covered framework of steel. It has two uprights which lie one on each side of the spine and which spread apart over the scapulae; they are joined transversely at the upper and lower ends or the appliance may be fashioned from one metal strip. At the upper end shoulder straps are attached and at the lower a broad pelvic leather band encircles the "truss line." In the middle there is usually an abdominal canvas or

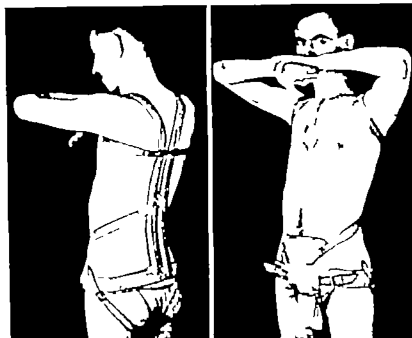


FIG. 148. *The Taylor Brace* as used in the convalescent treatment of spinal tuberculosis.

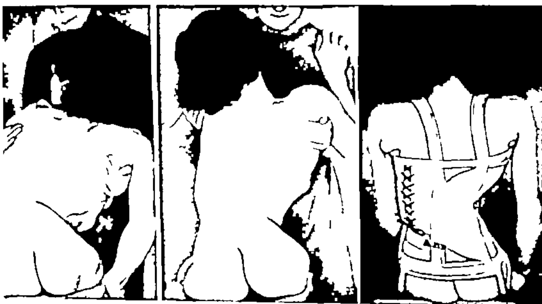


FIG. 149. Paralytic scoliosis with severe disability greatly helped by well made spinal support—note lateral gluteal extensions to chair seat.

leather corset which is attached to the support at the back. (*b*) The Taylor support has two uprights of spring steel which lie close to and on each side of the spinous processes. At the upper end the two uprights diverge towards the side of the neck and from them shoulder straps pass forward in front of the clavicle to be buckled to straps that come forward from beneath the axillæ and which are attached to the steel uprights in the interscapular region. At the waist line the uprights are attached by straps to a leather abdominal pad placed between the pubis and the umbilicus. At the back the uprights are fixed to a pelvic band of mild steel which is also attached by straps to the abdominal pad.

For more rigid control of lateral movement the *Fisher* or *Ernst Spinal Jacket* is used. In principle this resembles the Taylor support, but with the essential difference of having metal uprights fixed in the lateral line to the pelvic band below and having crutch supports beneath the axillæ at the upper ends. Although used with various types of pressure pad over kyphoscoliotic protruberances, such appliances have little efficiency in the treatment of structural scoliosis. Their chief usefulness is in the severely collapsing conditions seen in some forms of paralytic scoliosis.

There are innumerable variations of spinal appliances made upon similar lines but there is one special type which merits some consideration. This is the spinal extension appliance of Blount of Milwaukee, which is of special use in the incipient stages of juvenile structural scoliosis. Upon a leather pelvic girdle (specially made upon a plaster cast) are erected steel uprights which are not applied to the spine at all but which have attachment at their upper end to a framework lying under the chin and lower jaw in front, and under the occiput at the back. As the child grows, or the spine is straightened, the support can be elongated by adjustment of the extensible uprights. The position of the head supports is so adjusted that the child continually lifts itself out of the support, and so is constantly applying active correction to the curvature.

MANIPULATIVE TREATMENT

The whole of surgery is distinguished by manual procedures (*chirurgia* from *chiros*—the hand). Therapeutic manipulation as applied directly to the body of the patient should include massage, friction, tapping etc. which more often come within the scope of the physiotherapist. While the surgeon uses manipulation to realign a fracture or to reduce a dislocation, to restore movement to a stiff joint or to correct deformity, there are also innumerable occasions where mobilizing techniques are applicable to less clearly defined circumstances. In fact, to that borderline of functional defects which is the happy hunting ground of the charlatan who trades upon the "misplacements of little bones" and "slipped discs."

In the treatment of deformity we follow the principles of mobilization and correction with its maintenance by the re-education of muscular control. This must be applied to the minor manipulative measures, the main purpose being to overcome soft tissue contractures (most of them minor in degree and affecting muscles predominantly) and to restore tonus in the muscles. Perhaps it is because the majority of such lesions are objectively minor in degree that surgeons have paid too little attention to them. Yet subjectively the associated sensory disorders are clalmant and the muscular disabilities may be widespread.

The disabilities for treatment are chiefly of soft tissue character: intra and peri-articular adhesions, intermuscular fibrosis, muscular and capsular contractures, chronic

sprains and psychogenic or functional disorders. In addition there are cases of joint derangement due to the intra-articular locking of loose bodies or meniscal fragments. The pathology of the first group is uncertain. The probability of inflammatory reactions provoked generally by trauma and followed by fibrosis and occurring in synovial membranes, capsular ligaments, muscles, tendon sheaths etc. is the most likely Purely articular derangements are common enough but there are practitioners who would place the majority of the soft tissue lesions above mentioned into this group and regard them as examples of "subluxations" of various types. This idea is even more problematic than that given above.

In carrying out manipulative techniques it is important to know not only the normal range of movement of particular joints and the disposition and action of their controlling muscles It is also necessary to understand the less obvious passive mobility and distractability that can be obtained and may particularly be involved in the type of trauma which results in lesions such as we have mentioned.

Obviously it also is necessary to know what force may safely be applied and the methods of applying it in the directions required. Generally speaking movements, whether in the conscious patient or under anæsthesia, should be firm and smooth and without violence or sudden jerks most manipulations can and should be performed without anæsthetic providing that the patient's confidence can be combined with relaxation. In many cases, however where relaxation is difficult or pain is severe (in particular in certain joints) the surgeon should be prepared to manipulate under anæsthesia.

It is inappropriate in the present work to describe all the manipulative procedures used, because the scope is so extensive and furthermore because the practice is best learnt by observation and experience. It must be emphasized that safe manipulation must be preceded by accurate diagnosis. Furthermore amongst the contributory factors a search should be made for focal sepsis in particular dental infection should be treated.

The Spine. Although the intervertebral joints comprise in the main 3 elements (two interlaminal and one intercentral) the spine moves as a whole. Mobility varies in each area, cervical, dorsal and lumbar but movement of one part involves the remainder to a greater or lesser degree Furthermore, because the spine has normal fixed antero-posterior curvatures, lateral movements involve torsion and vice versa.

Relative fixation of one part may increase the mobility in another and knowledge of this is made use of when particular areas are manipulated. The elasticity of the inter vertebral fibro-cartilagenous discs allows some elongation to occur under traction a procedure of great antiquity and one that is used either dynamically as part of spinal manipulations or more statically upon a bed for longer periods. It is also part of remedial gymnastics and can be employed in the home by patients in the treatment of spondylosis particularly in the neck.

The chief movements to be carried out in the spine are six antero-posterior flexion and extension, lateral flexion and torsion to each side. There are subsidiary movements, such as distraction and lateral or antero-posterior shifts. With manipulation of spinal joints the surgeon is also bound to influence the costo-vertebral and sacro-iliac joints, their ligaments and the controlling musculature of the whole complex system. Some of the manœuvres are illustrated. It is essential to recognize that dangerous forces can be exerted upon the relaxed spine whether or not the patient is under an anæsthetic the

danger being a little different in each case without an anæsthetic the soft tissue and intervertebral discs are at risk and, under anæsthetic, so is the bony structure Therefore, with understanding of the pathological process involved and the normal mobility of joints the manœuvres must be conducted slowly firmly and without violence.

The Hip. Generally manipulation is done for osteoarthritic joints especially in the earlier stages. Nevertheless, even in late cases judicious movement is worth while to stretch muscles (which have been in spasm) and the joint capsule and ligaments and even to stretch intra-articular bands or adhesions.

As with the spine it is helpful to combine distraction with each phase of antero-posterior and lateral movement, but in all movements of the hip (whether flexion, extension, abduction, adduction or rotation and combined movements) the surgeon must guard the knee joint which may be strained if the grip upon the limb is made without considering this.

The Knee. As with other joints minor derangements are often difficult to assess in relation to the causal mechanism. Meniscal displacements are a separate subject, but there are other lesions which can only be described as being the result of intra-articular ligamentous or intra-muscular adhesions due to fibrosis following minor traumatic hæmorrhage and inflammatory reactions. The part played by focal infection as a contributory factor should be borne in mind.

Distraction again is an important element in manipulation and is combined with flexion and rotatory movements and extension with and abduction and adduction rocking of the tibia upon the femur Furthermore antero-posterior shift movements should be carried out in all phases of flexion and extension. In meniscus lesions special short quick movements may be applied for special types, e.g. sharp extension with abduction and internal rotation of the tibia in medial meniscus lesions sometimes sharp quick flexion at its extreme range may dislodge a partially displaced anterior meniscus segment.

The Ankle and Foot. *The particular indications for manipulation are* "chronic sprains" especially that on the antero-lateral aspect of the ankle following injury to the fibular collateral ligaments. Movement of all the joints of the foot should be given through their entire range in turn, starting from the forefoot with the heel fixed and then with the heel free Special reason for such mobilization is found in the persistently stiff and painful tarsal joints following immobilization of the foot in the treatment of fractures of the lower extremity Special caution must be exercised, however when there is gross stiffness or where the bones are in an osteoporotic state Repeated fractional manipulations gaining small improvements are better than too intensive single treatments. A third important reason for manipulation of the foot is in chronic foot strain or painful flat-foot. Flat foot" or "Pes Planus" is frequently a misnomer and is consequently mistreated with arch supports. The shape of the foot is less important than the efficiency of its muscular control. The latter may be overstrained and develop spasm, atrophy and fibrosis associated with joint adhesions and pain in the long and metatarsal arches. Manipulative treatment as described above and including the metatarsal and toe joints is of great benefit if associated with temporary support and a thorough programme of remedial exercises.

The Shoulder Elsewhere the complexities of the pathology of the stiff shoulder is discussed. Here it may be emphasized that the most favourable case for manipulation is that with limitation of a small part of the normal range The least satisfactory cases

are those included under the bad colloquialism—"frozen shoulder" These very stiff shoulders appear to have adhesive scarring between the humeral head and the rotator cuff and within the subacromial bursa and biceps sheath. There is usually muscular wasting and marked osteoporosis of the humerus. If manipulation is carried out in this type of case it must be done in easy stages and followed by careful active supported exercises. Reactions are common, but these may be alleviated by injections of hydrocortisone into the subacromial bursa. Even with the less extensive stiff shoulder the manœuvres must be conducted with care. There is a special place for the use of traction to stretch lengthwise the capsular tissues but with it there must be adequate counter traction, particularly with the anæsthetized patient, so as to avoid risk of damage to the brachial plexus. With such traction each range of normal movement is carefully explored and any resistance is gently stretched by coaxing rather than by force

As will be described elsewhere there are some cases of acutely painful stiff shoulder which are best treated in the early stages by rest

The Elbow The special indications for manipulation are the chronic occupational strains often called "tennis elbow" Epicondylitis of the lateral epicondyle, intramuscular fibrosis in the extensors of the wrist and inflammatory adhesions in the region of the semicircular synovial fringe of the radio-capitellar joint lead to pain in extension of the elbow with pronation and flexion of the wrist. Adduction of the elbow through the complete range of flexion and extension is emphasized with pronation of the forearm and flexion of the wrist and fingers.

The Wrist. The surgeon must eliminate such causes for chronic pain as the ununited fracture of the scaphoid, subluxation of the first carpo-metacarpal joint, and stenosing teno-vaginitis of the lateral radial sheaths, and lunate malacia. Manipulation of the wrist is useful for chronic occupational strains or for joint adhesions. The normal movements of the wrist should be carried through their normal range with combinations of obliquity and with antero-posterior and lateral shift movements combined with traction.

SURGICAL EXPOSURES OF BONES AND JOINTS

As in all surgical operations those involving bones or joints must be carried out with precision, gentleness, hæmostasis and the utmost regard for asepsis. The unnecessary handling of tissues is to be avoided but a slavish adherence to so-called "non-touch" techniques at the expense of tissue damage by harsh metallic instruments is to be deprecated. Nevertheless, the susceptibility to infection of bones and joints, should be appreciated. Compared with an abscess within soft tissue planes an acute infective arthritis or osteomyelitis may lead to the most crippling disability the severity of which is all the greater because most of the operations of orthopædics belong to the "elective" type. Approaches to bones, therefore, should be as far as possible atraumatic by incisions passing through intermuscular planes and the careful observation and control of vascular supply and drainage. In this work we will not describe every possible surgical exposure but will concentrate upon the more important ones.

Shoulder Joint. For limited exposures of the front of this joint an almost vertical incision is used along the anterior border of the deltoid and the interval between this and the pectoral muscles is deepened to the front of the capsule. The exposure is improved by extending the incision at the upper end along the margin of the acromion laterally and reflecting a portion of the deltoid. It is improved also by detaching the short head of the

biceps and coracobrachialis *muscles from the coracoid process. Besides avoiding the* main axillary vessels and nerves care must be taken of the anterior circumflex vessels. A disadvantage of the vertical anterior incision is its liability to keloid change. Where a wider exposure is desirable as for example in arthrodesis, it is better to make a horseshoe shaped incision below and almost parallel with the outer clavicle and acromion. The upper skin flap is elevated so that the deltoid muscle may be turned downwards from these bones. The rotator cuff and capsule is incised in the line of and lateral to the tendon of the long head of the biceps and the two halves of the cuff are turned medially and laterally off the lesser and greater tuberosities.

An approach behind the deltoid has been used for arthrodesis. The risks of damage to the deltoid nerve supply (circumflex) which emerges from the quadrilateral space is then not so serious

The Humeral Shaft. The same interval as for the front approach to the shoulder can be extended down to the insertion of the deltoid and between it and the biceps and then *downwards still further splitting vertically the brachialis anterior muscle between its* lateral (radial nerve supplied) and medial (musculo-cutaneous) portions.

The Elbow Joint. Exposure is most often required for the removal of loose bodies and for the excision of the head of the radius. For both purposes a *lateral incision* is best, with its centre over the lateral epicondyle. The joint is then opened either in front or behind the radial collateral ligament. In front some of the radial carpal extensor muscles fibres may be elevated with the capsule from the humerus. At its lower end the excision must not extend so far as to risk damage to the posterior interosseus branch of the radial nerve. Exposure of the inner side of the elbow is rarely required except in transposition of the ulnar nerve forwards from its groove and for the transposition to a higher level of the wrist flexor muscle origins in cases of elbow flexor paralysis (Steindler's operation). In neither operation is it necessary to open the joint.

Head and Neck of Radius. Where a better exposure is required of the neck of the radius, with less risk of damage to the branches of the radial nerve, it should be gained *through an anterior incision deepened between the biceps tendon and brachialis muscles* on the medial side and the brachio-radialis and radial carpal extensors laterally It is necessary to have care for the lateral cutaneous nerve and to expose carefully and go between the radial vessels medially and the radial nerve laterally The neck of the radius is stripped medial to the insertion of the supinator brevis.

The Shaft of the Radius. The above anterior incision is extended downwards along the anterior ridge of the radius to the pronator teres insertion and then, lateral to the radial vessels, along the antero-lateral border down to the styloid process and the insertion of the brachio-radialis—the superficial continuation of the radial nerve being carefully watched

The Ulna. For the olecranon a mid line posterior incision may be used but for the avoidance of an adherent subcutaneous scar it is better to make a U-shaped incision convex upwards with its centre above the tip of the bone enabling adequate exposure of fractures and their fixation.

The Shaft of the Ulna. Incisions are best made to the medial side of the subcutaneous border with elevation of the flexor carpi ulnaris.

The Wrist Joint. For arthrodesis a dorsal incision vertically in the mid-line of the bone passes through the posterior *annular ligament* between the extensor pollicis longus

laterally and the extensor digitorum communis etc medially When the incision is extended upwards for the removal of a graft for the purposes of the arthrodesis care must be taken of the tendon and muscle belly of the long thumb extensor

The Hand. The special problems of skin incisions and exposures is dealt with in the appropriate section, Volume III p 293

The Spine. Mid-line incisions over the spinous processes are everywhere satisfactory allowing good exposure of the laminæ and the meninges and nerve roots and lateral intervertebral foramen—after laminectomy Such wounds heal perfectly It unnecessarily complicates spinal exposure to curve incisions to either side of the spine.

Spinal Arthrodesis or Fusion. The original Albee operation consisted of a single autogenous tibial graft placed in a bed prepared by splitting vertically the spinous processes and interspinous ligaments through a mid-line incision. Russell Hibbs developed a precise technique which excised the articular surfaces of the posterior intervertebral joints and elevated and overlapped thick slivers of bone raised from the laminæ and spinous processes.

Present day practice is generally to combine these two methods using for grafting material bone taken either from the tibia or from the ilium. Stored frozen homogenous bone is sometimes used, particularly if for any reason it is not practicable to use the patient s own bone. It is not, however as reliable as autogenous material.

A vertical mid line incision is made over the area to be fused and the muscular and aponeurotic structures are dissected off the spinous processes by subperiosteal stripping and is continued until the posterior surfaces of the articular process are cleared. Each side is dealt with in stages, so that hæmorrhage which might otherwise be troublesome is arrested by packing between the muscles and the spinous processes for a few minutes. The remains of the interspinous ligaments are completely excised, then slivers of bone are raised from the surfaces of the laminæ and turned laterally If three or four or more vertebræ are to be fused two grafts of requisite length are taken from the entire cortical thickness of the subcutaneous surface of the tibia. For the fusion of two vertebræ the lower and upper edges respectively of the two spinous processes are completely bared and notched Then after the laminæ have been dealt with as described above a thick cortical and cancellous graft is taken from the posterior portion of the patient s ilium. It is shaped into the form of a letter H the transverse portion being just small enough to fit into the interspinous gap prepared for it. This process is facilitated by flexing the patient s spine. When the spine is extended after embedding the graft the latter becomes completely locked into position.

Costo-transversectomy This operation has been most commonly used for the drainage of paravertebral abscess in tuberculosis of the spine with paraplegia due to inflammatory rather than purely mechanical causes. Wilkinson has however been a strong advocate of this operation combined with curettage of the vertebral lesion in non-paralytic cases not responding well to purely conservative treatment. Griffiths, Seddon and Roaf have gone further and have stated that it should be performed in all cases in which the radiographs show an abscess and if the disease is recent.

The surgical approach is through an incision convex to the side of the kyphus and the trapezius muscle is reflected laterally from the spine. The lateral portion of the sacrospinalis muscle is split vertically and the rib leading to the main vertebral lesion is stripped subperiosteally and followed to the transverse process with which it articulates. This

process is then excised to its junction with the lamina and then the stripping of the rib is continued medially towards its head. After cutting the rib at its angle the central portion can now be mobilized and removed. During this process the para-vertebral abscess will have been opened and can be evacuated by irrigation combined with suction.

For the further extension of this operation into the vertebral bodies see *Lateral Rhachotomy* on p 310.

Exploration of the Sacro-iliac Joint is best performed through an incision along the posterior quarter of the iliac crest and extending downwards from the posterior superior iliac spine on to the buttock. The gluteal muscles are stripped subperiosteally downwards and forwards off the posterior part of the ilium to the great sciatic notch where special care must be taken not to damage the ascending branch of the superior gluteal artery which lies quite close to the upper margin of the notch. An inch above and parallel to this margin an oblong hole is made through the ilium down to the sacro-iliac articulation. After curettage of the joint, bone removed from the ilium may be counter sunk into the lateral mass of the sacrum in order to facilitate arthrodesis (Smith Petersen's method).

Laminectomy is required in exploring the contents of the spinal canal. In orthopædics the chief indication for it is for the removal of protrusions of intervertebral disc material less commonly for intra-spinal neoplasm and occasionally for the removal of bony fragments displaced into the spinal canal in fractures or fracture-dislocations with neurological signs. In intervertebral disc surgery it may be possible to deal with protrusions by an extremely small, and sometimes even with no removal of laminar substance. A mid-line incision is used and the vertebral muscles are stripped subperiosteally from the spinous processes above and below the interval to be explored. Bleeding from the exposed surfaces is readily controlled by temporary gauze packing. The interspinous ligament and the ligamentum flavum are excised to expose extra thecal fatty areolar tissue beneath which is the tough bluish dura mater Nibbling away the upper and lower edges of the contiguous laminæ may be sufficient to allow the theca gently to be retracted to expose an affected nerve root in its thecal sheath and to permit excision of the protruding disc substance If the spinous processes are preserved *in situ* it will facilitate the fixation of a short bone graft if it is desired to fuse the two vertebræ involved. Often a wider exposure is necessary and then the whole of the 5th lumbar spinous process and lamina is excised with special laminectomy rongeurs together with sufficient of the laminæ of the fourth lumbar and first sacral vertebræ. In this way adequate exploration may be given to protrusions at the two most frequently affected intervals. For spinal cord tumours and traumatic cases a much more extensive exposure will generally be required.

Excision of the Ilium may be required for tumours in particular chondromata or myelomata. Very occasionally the operation has a place in the treatment of chronic pyogenic osteomyelitis. The incision extends along the whole length of the iliac crest and a little below both the anterior and posterior superior iliac spines. The gluteal and pelvic faces of the bone are then stripped of muscles as far as possible subperiosteally This can be carried right down to the pelvic brim and backwards to the sacro-iliac joint. If in order to remove the tumour the continuity of the pelvic brim must be broken then the area must be bridged by bone grafts taken from the tibia perhaps re-inforced by homogenous tissue from a bone bank. In such cases however the utmost care must be

taken in cases of bone tumour to ensure that there is no contamination of the donor area. The precautions taken must be of the most rigid type

Approaches to the Hip Joint

The depth of the hip joint from the surface, and the close relation to it of important vessels and nerves both anteriorly and posteriorly have led to the development of a

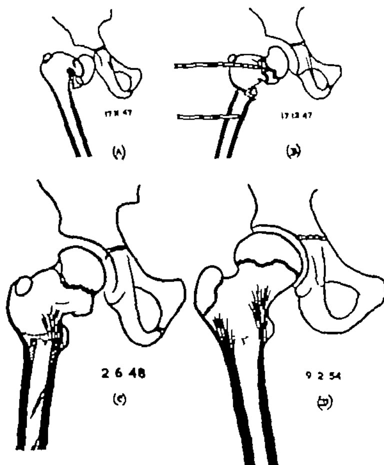


FIG. 150. *Methods of dealing with Typical Orthopædic Surgical Problems. Hip Operations I* Radiographic tracings in a case of congenital coxa vara (*a*) Before operation (*b*) immediately after operating showing use of transfixion pins which are incorporated in plaster (*c*) six months after operation Upon the shaft are indicated stress lines which appear clearly in the original radiographs and demonstrate the transference of body weight to the outer diaphyseal cortex (*d*) six years after operation.

variety of approaches, all more or less from the lateral aspect. These approaches are usually described as antero-lateral or postero-lateral In the superficial part of each the essential difference is that in one the tensor fascia femoris muscle is behind the incision, and in the other it is in front. Each approach has its own special advantages and some surgeons have sought to obtain the advantages of both by making curved transverse incisions which involve the elevation of the tensor muscle after dividing its attachment

to the fascia lata. A noteworthy study of this subject was made by E. G. Brackett in 1912. He gave an admirable exposition and, in his avoidance of eponyms it is clear that even then the usual approaches had already achieved classic status.

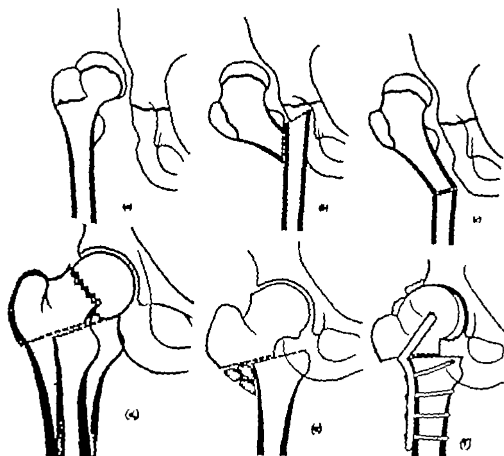


Fig. 151 *Hip Operations 2.* (*a*) Congenital dislocation of the hip (*b*) Hypothetical Lorenz bifurcation osteotomy (*c*) Hypothetical Schanz osteotomy *The Schanz osteotomy with its inferior pelvic* support gives better mobility particularly if the angle of the line between the medial articular surface of the femoral head to the osteotomy and the line of the femoral shaft is less than the angle of lateral pelvic obliquity (*d*) The Lorenz-McMurray *osteotomy for femoral neck fractures* The dark outline shows the pre-operative condition of non-union with a partially avascular femoral head. The fainter outline shows the altered relations after osteotomy Fusion in this position gave a first class functional result. ( ) The *Lorenz-McMurray osteotomy for osteoarthritis* while it is not expected that the movement of the joint will be improved, the relief to the patient is gained by the available correction of deformity and improved weight-bearing alignment, and consequent economy of muscular effort Other reasons for improvement have also been claimed. (*f*) Showing use of nail plate for fixation of fragments which permits early ambulation in a single plaster spica.

Postero-Lateral Approach. Langenbeck is credited with having first used a limited incision obliquely through the gluteus maximus for drainage of the hip joint. It was developed by Kocher and Brackett who both approached the hip joint through the anatomical plane between the gluteus maximus and the tensor fascia femoris. In this approach, in order to get a complete exposure of all the components of the hip joint, it is necessary to detach the gluteus medius and the gluteus minimus with the short external

rotator muscles from the great trochanter or better to turn up the latter with the gluteus medius, minimus, and pyriformis.

Amongst recent writers Gibson (1950) has revived interest in this approach which gives perfection of access to the hip joint by an almost avascular route

Recently McFarland and Osborne have given a further exposition of this approach with the interesting variation of reflecting the gluteus medius and the upper portion of the vastus lateralis and the periosteal tendinous covering of the great trochanter in one sheet from behind forwards.

Antero-Lateral Approach. The classical antero-lateral approach is that sometimes associated with the name of Hüter The skin incision extends from the anterior superior

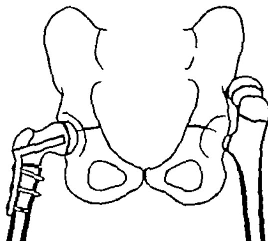


FIG. 152. *Hip Operations 3* The use of the miniature nail-plate as advocated by Blundell Jones for coxa valga in paralytic dislocations.

spine downwards and the intermuscular plane of the tensor fascia lata and the sartorius is deepened to the rectus femoris tendon and to the capsule of the hip joint. This incision gives a somewhat restricted view of the anterior aspect of the hip joint. It was extended upwards and outwards by detachment of the anterior portion of the gluteal muscles from the lateral surface of the ilium by Sprengel, but it was Smith Petersen who fully developed the possibilities of this approach by detaching the rectus femoris tendon from the anterior inferior spine and the abdominal and iliacus muscles from the inner surface of the anterior portion of the ilium.

Lateral Approaches. These really combine features of both the anterior and posterior approaches. The chief of these is Ollier s curved transverse incision which is made convex downwards. This was converted into a goblet-shaped incision by Murphy who added a vertical extension downwards from the lowest point of the convexity along the line of the shaft of the femur In both, after elevation of the tensor fascia femoris muscle the exposure of the hip joint was facilitated as in the Kocher incision by elevation of the great trochanter

Conclusions. It is worth emphasizing that the frontier zone in all the approaches to the hip joint is provided by the tensor fascia femoris muscle. The advantage of the short

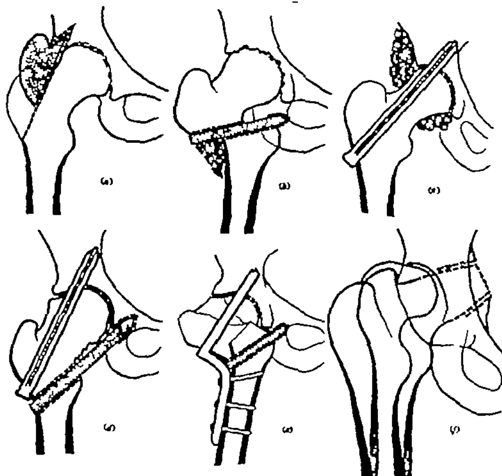


FIG 153 *Hip Operations 4* (*a*) Ilio-femoral arthrodesis with lateral graft. The principle originated by Hibbs and Albee. In osteoarthritis the graft, as illustrated, was placed close to the femoral head. All lateral extra-articular grafts have the disadvantages of the tension produced by the adducting force upon the weight-bearing hip. For osteoarthritis the results were unsatisfactory (*b*) The ischio-femoral arthrodesis of Brittain. This procedure is more suitable in joints of "atrophic" type and in quiescent tuberculosis. The displacement osteotomy permits correction of deformity and the medial position of the shaft ensures contact throughout the interposed bone graft with compression. (*c*) Arthrodesis of the hip. *Showing use of large* trifin nail which transfixes *the joint after removal of all articular cartilage* and cortical bone. Early attempts at arthrodesis by nail alone proved unsuccessful because the biological conditions for bony fusion were not satisfied (*d*) The V-arthrodesis of Brittain. A long trifin transfixes the joint. Intra-articular interference is avoided and its defects are mitigated by the approximation of graft to the under surface of the femoral neck. This graft which lies within hole in the femoral shaft enters the ischium close to the acetabulum (*e*) Arthrodesis by combined osteotomy and nail-plate fixation with ischio-femoral graft in a case of osteoarthritis associated with severe adduction deformity. A previous osteotomy alone had not relieved pain (*f*) Central displacement arthrodesis of Charnley. *Pre-operative condition in dark outline post-operative displacement in fainter out line.* The head and neck, reduced in diameter is passed into hole cut through the acetabulum at predetermined point so as to correct deformity. Abutment of the great trochanter against the outer margin of the acetabulum limits penetration and helps to maintain fixation. Early fusion is obtained by the compressive effect of body-weight which is displaced relatively laterally upon the femoral shaft. The originator has also used spring loaded devices to increase the compressive effect

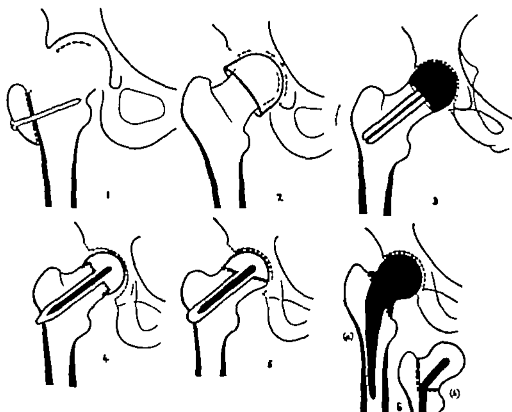


FIG. 154. *Hip Operations 5* (1) Whitman reconstruction. Originated as a method of treating cases of un-united subcapital fractures it was also the method employed by Platt and Bristow in their reports upon reconstructive operations in the early 1920's. Transposition of the great trochanter mitigated the femoral neck shortening. The acetabulum was untouched, mechanical congruity was imperfect and there must be some doubt upon the matter of lubrication. (2) The Smith-Petersen cup arthroplasty In the originator's own work he stressed the need to "conserve stock. Particular care was taken to avoid damage to the blood supply and undue shortening of the femoral neck, the great trochanter was not transposed and there was minimal interference with the gluteal muscles. It was essential, he said, to reconstruct and deepen the acetabulum. The metal cup had two functions (1) The biological one of separating two cancellous bone surfaces while they were being covered by new fibrocartilage ( ) the mechanical one of providing two extra bearing surfaces upon which movement of the articular surfaces could take place. (3) The Fitzgerald metallic prosthesis is two-piece device comprising hollow spherical portion to which the surgeon attaches at operation trifin nail of appropriate length. There need be no shortening of the femoral neck. It is generally not necessary to reshape the acetabulum. The metal sphere covers the reduced femoral head and there is movement only between it and the acetabulum. (4) The Judet prosthesis. Precise reshaping of the femoral neck after partial removal of the head, central placing of the stem of the appliance which must penetrate the lateral femoral cortex. The central metal rod strengthens the appliance. The acetabulum is reamed and deepened. Femoral neck leverage is preserved. (5) The Judet modified prosthesis. Designed to avoid dependence upon the cervical cancellous bone for marginal support with better mechanical properties of weight transmission by the diminution of shear between the head of the prosthesis and the femoral neck and by preservation of the medial diaphyseal support. (6) Two types of intra-medullary stemmed prosthesis (a) Thompson's made entirely of metal is applied after complete excision of the femoral head and neck down to the inter-trochanteric line. Resting on the cut surface, the metal prosthesis has a long tapering stem which bears against the lateral diaphyseal cortex (b) Merle d'Aubigné prosthesis with acrylic head and neck resting against medial vertical and horizontal cuts made through the inter-trochanteric area and having an angulated metal rod extending down the femoral shaft in similar manner to ( ).

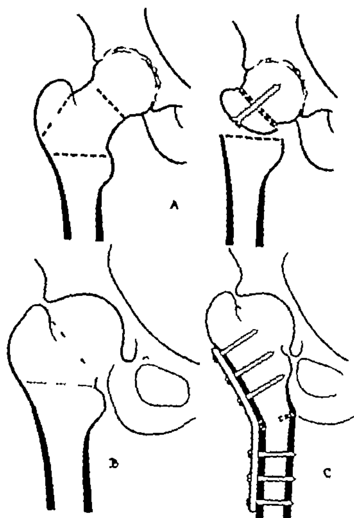


FIG 155. *Hip Operations 6* (A) Robert Jones pseudoarthrosis. Excision of the femoral neck and inter-trochanteric region and attachment of the great trochanter with its muscles to the under side of the femoral head gave mobility at the expense of stability and power. This was the basic pseudoarthrosis from which other types have evolved. (B) Girdlestone pseudoarthrosis. In its earlier form comprised excision of the entire head, neck and great trochanter leaving a transverse section above the lesser trochanter; the gluteal abductor muscles were attached to the lateral side of the stump. As later used the great trochanter was left intact with the shaft without interference with its muscular attachments. In both methods some muscular control of the femur was obtained but there was shortening and some instability. (C) The Milch-Batchelor excision osteotomy. Excision of the femoral head and neck was followed by subtrochanteric osteotomy of the Schanz type the measured angulation being held with a suitable metal plate. In a single hip a wider degree of abduction angulation is permissible than with a double hip operation.

classical antero-lateral approach is that *no muscles are detached* and of the longer Smith-Petersen approach that a complete exposure is possible for reconstructive surgery The latter however has the disadvantage that re-attachment of the gluteal muscles to the lateral surface of the ilium is difficult to secure, particularly in adult patients The postero-lateral approach has many advantages in being a very clean and quick method of giving a wide exposure of the hip joint, and it is very readily closed. In all the approaches, detachment of the great trochanter offers the possibility of replacement at a lower level on the *femoral shaft if the operation has necessitated some* shortening of the femoral cervical leverage For details of the operation of arthrodesis of the hip *see* p 260 and for trochanteric osteotomy *see* p. 258

The Shaft of the Femur should be approached through a postero-lateral incision which follows the plane of the lateral intermuscular septum down to the *linea aspera.* The fascia femoris is split posterior to the line of the ilio-tibial band and the interval between the vastus lateralis and the intermuscular septum is followed down to the bone. *By this means the entire length of the femoral shaft* from the trochanters to the lateral femoral condyle may be exposed without any risk to the nerve supply of the vastus lateralis muscle which may be stripped off the lateral surface of the femur by subperiosteal dissection. Perforating vessels issuing from the other side of the intermuscular septum must be noted and controlled.

Exposures of the Knee Joint. Arthrotomy is most commonly required for menisectomy for which the usual incisions are almost vertical on either side of the patella, and the infra-patellar fat pads. Incisions which divide transversely the fibres of the quadriceps aponeurosis are less suited for a post operative course which favours early movement (see also in the section upon the knee, Chapter XIII). For wider exposures of the knee joint, as for example in synovectomy or arthrodesis, a long paramedian incision which skirts the inner margin of the patella and extends from about four inches above the upper margin of this bone to a point about an inch or so below the tibial tubercle, allows the patella to be displaced laterally and even to be everted upon the outer side of the lateral femoral condyle. Medial displacement of the patella is not convenient.

The posterior compartments of the knee may be approached immediately behind the collateral ligaments and in front of the hamstring muscles.

For posterior capsulotomy or capsuloplasty these two incisions can be extended a short distance up the thigh so as to enable *the posterior capsule and the popliteal periosteum* to be stripped from the femur

The Shaft of the Tibia. It is all too easy to expose this through its subcutaneous surface A curved incision lying mostly in front of or behind this surface is advisable and a suitable skin flap retracted. In some cases as, for example, in metaphyseal infec *tions it is better to expose the posterior* surface of the tibia through an incision behind its medial border

The Ankle. Generally a lateral approach is used for arthrodesis, the *incision extending* upwards along the posterior border of the fibula and across forwards below its tip. An anterior skin flap is elevated with the deep fascia and the extensor tendons of the toes *are elevated.* A posterior approach may be used lateral to the tendo achilles for access to the posterior part of the joint or behind and below the medial malleolus *for fixation* by screws of fractures of this portion of the tibia.

The Sub-taloid and Mid-tarsal Joints. The Kocher lateral incision is employed. This curves forwards from behind the lateral malleolus across the lateral surface of the calcaneum and on to the outer area of the dorsum of the foot. The tendons of the

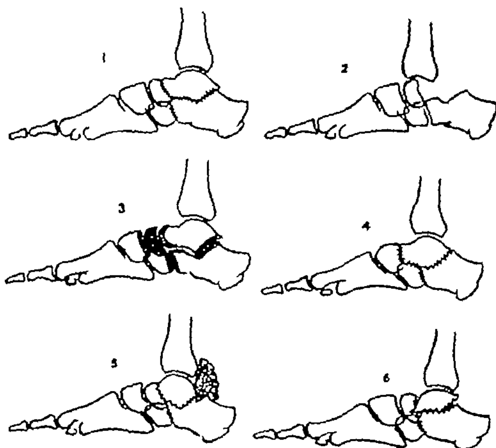


FIG. 156. *The Principle of Stabilizing Operations Upon the Foot*

(1) Triple arthrodesis.
(2) Whitman's astragalectomy
(3) The amount of bone removed in Dunn's arthrodesis.
(4) The result of Dunn's arthrodesis.
(5) Campbell's bone block
(6) Lambrinudi's operation.

The ability to correct deformity and achieve stability is given by triple or subtaloid arthrodesis. Whitman's procedure shortened the forefoot and lengthened the hindfoot levers. Of value in calcaneo valgus it has been superseded by Dunn's or other similar operations, which achieve a similar mechanical effect with greater stability. Campbell's and Lambrinudi's operations for drop foot achieve lateral stability with a mechanical block to plantar flexion. In Lambrinudi's procedure this is done by tilting the body of the talus sharply so that its posterior margin locks in the tibial mortise.

peroneus longus and brevis and the external lateral ligament are divided and the outer border of the extensor digitorum brevis is found and this muscle with the lateral attachments of the anterior retinacular fascia is reflected medially off the upper surface of the neck of the calcaneum and cuboid bones The lateral surface of the neck of the talus is

exposed and the interosseus ligament and the Haversian fat pad is removed from the tarsal sinus. The dorsal calcaneo-cuboid and calcaneo-navicular ligaments are stripped from the dorsal surfaces of the bones. It should now be possible by forced inversion to open up the sub-taloid and mid tarsal joints like a book and the appropriate procedure performed such as triple arthrodesis

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CHAPTER VIII

GENERAL DISEASES OF BONE

LAWSON DICK

BONE is the calcified end-product of pluripotential mesenchymal cells. It is essentially a connective tissue but it differs from all other connective tissue in its power of adsorbing and incorporating into its structure crystalline calcium which it extracts from the blood serum where the calcium is contained in organic solution Further bone is the only differentiated tissue in the body in which wounds heal by complete reconstitution of the original structure of the wounded tissue without leaving an undifferentiated fibrous scar to mark the original site of the wound. Bone must possess this property in order to perform adequately its function as a framework for the body Fibrous scars can not withstand stresses, and if fractures healed by scar formation as do wounds of other tissues every fracture would result in a permanent weakening of the skeleton.

The manner in which bone grows and is repaired has been discussed (pp 226–229). To recapitulate briefly the factors, apart from blood supply which influence the general processes of growth and repair in bone are

1 qualities inherent in the mesenchymal cells
2. hormones
3 vitamins
4 external stress.

When the pluripotential cells of the mesenchyme are differentiated into bone cells they are changed not so much in respect of their structure, although there are recognizable differences in structure between the various cells associated with bone growth and repair as in respect of their function.

The three types of bone cells are

1 Osteocytes. These are adult bone cells. They are irregularly shaped mono-nucleated cells with long attached fibrils which are interspersed amongst the portions of bone with which they are associated. They have not the power of reproduction or multiplication of themselves by binary fission. Like red blood corpuscles they have a limited span of life. When they die, the portion of bone with which they are associated dies with them and is absorbed by osteoclastic activity and replaced by osteoblastic activity under the control of the factors detailed above

2. Osteoclasts. When a portion of bone dies, mesenchymal cells are differentiated into cells called osteoclasts which are capable of removing such dead bone. These are large multinucleated cells—having thirty or more nuclei—akin in appearance, as in function, to foreign body giant cells. When they have completed the removal of the now lifeless portion of bone their function is at an end and they die in their turn

Osteoclastic activity is an essential part of the remodelling process which goes on in all growing bone, is responsible for the tubulation or "waist-like" shaping of the shafts

of long bones—its absence may be noted in the cylindrical shape of the ends of the metaphyses in diaphysial aclasia or in the shafts of the short long bones the metacarpals or metatarsals, in osteopetrosis or achondroplasia—and for the normal shaping of areas of bone of complex or irregular structure such as the angle of the jaw or the upper end of the femur

3 Osteoblasts. When bone has to be formed, as in *endrochondral ossification* at growing epiphyses, or when it has to be replaced or added to the process known as *appositional ossification*, mesenchymal cells are differentiated into osteoblasts. These are large mononucleated cells which have the power of releasing an enzyme known as alkaline phosphatase This enzyme, probably in part by changing the hydrogen ion concentration in the neighbourhood of the osteoblast, brings about the precipitation as crystalline calcium of the inorganic calcium in solution in the serum The precipitate is known as dahlite, a loose compound of the carbonate and the phosphate of calcium with the probable formula $CaCO_3$, $2Ca_3(PO_4)_2$. When they have performed this function the osteoblasts either die and are replaced by adult bone cells or osteocytes, or more probably undergo a further functional change which is accompanied by some morphological change. The bodies of the cells shrink somewhat, they develop long tendrils, and become osteocytes in which form they finish their span of life

Much of the difficulty in understanding and in classifying the various anomalies of the skeleton will be overcome if these simple principles of the normal physiology of bone are understood and applied

(1) All cells which are locally concerned with bone growth and repair are derived from a common pluripotential mesenchymal ancestor and are functionally differentiated in accordance with local needs and conditions.

(2) The normal operation of the process is dependent upon inherent qualities in the parent mesenchyme in which defects may appear either generally or locally and on the effect of extrinsic influences, hormonal, nutritional or mechanical.

(3) Bone is continuously in a physiologically dynamic state known as excitability and is therefore resilient in a way which it could not be if it were, as older concepts had it, a relatively inert structure. The simile of the child s spinning top may serve to illustrate this point. If the top is stationary and balanced on its tip, symbolizing the inert state of living matter it is easily upset and overthrown. On the other hand, a rotating top balanced on its tip, symbolizing the dynamic state of living matter is not easily upset by external influences. Forces tending to push it over may make it tremble a little but whilst it continues to rotate it soon rights itself The simile is not perfect. Like most attempts to explain a chemical or physico-chemical process by an analogy which is purely physical it is not complete, but it serves to illustrate the physical resilience, reparative power and adaptability of bone in the dynamic state The understanding of these mechanisms has, in the past fifteen years, been greatly facilitated by the use of radioactive isotopes, notably by observations on the uptake by skeletal tissues of radioactive phosphorus.

This state of dynamic vitality of bone accounts for the well known phenomenon of the modelling of the growing skeleton. This was first observed by John Hunter and was described by him with faithful accuracy though he could not explain the mechanism whereby it comes about. He wrote "the remote cause of absorption of whole and living parts implies the existence of two conditions, the first of which is a consciousness in the

part to be absorbed, or the unfitness or impossibility of remaining under such circumstances, whatever they may be, and therefore they become ready for removal and submit to it with ease And the second is the consciousness of the absorbents of such a state in the parts. Both of these concurring they have nothing to do but to set to work."

This was a truly remarkable piece of observation on the part of one who did not have a microscope and who could not have known of bone cells. It also explains the migration of teeth in the jaw when they are subjected to stress—this property of bone is used by the orthodontist when he applies continuous elastic pressure to correct the alignment of an irregular dentition—and it explains osteoporosis and hypertrophy of bone.

Osteoporosis of bone is essentially due to a failure of osteoblastic appositional activity When bone is deprived of the mechanical stimulus which is needed for the maintenance of the cycle of growth, death and replacement, the process fails at the level of osteoblastic reforming of the worn-out bone segments. The bone therefore becomes porotic and thin, lacking in the normal calcium content and brittle. It must be emphasized, however that the process is more than a decalcification—it is an actual alteration of bone structure. The condition is seen in any form of disorder associated with muscular inaction. In a limb paralysed by poliomyelitis the bones are of normal shape and are normally modelled, and epiphysial fusion occurs at the normal time, but they are small, thin and weak. The ultimate shape of the bone may not be quite normal because of the absence of normal stresses—this explains the valgus femoral neck in young children with gluteal palsies—but the essential modelling process is not disturbed although the bone is porotic.

A similar defect occurs in an adult bone, in which growth in size is at an end, when it is deprived of the stress stimulus by paralysis or by splinting. It is important to note that the disuse atrophy of the skeleton of a splinted limb may be prevented by repeated contractions of the muscles of the limb It does not matter that the joints do not move. The pull of the contracting muscles provides enough stimulus to maintain the balance between bone destruction and bone formation.

Hypertrophy of bone is produced by a similar but exactly opposite mechanism. Extra stress applied to bone causes increased osteoblastic activity Increased bone formation and consequent increase in size of the affected bone. This phenomenon is seen when a fibula is transplanted into a tibia to bridge a gap or when a bone graft is subjected to a compression stress which it can withstand. The degree of the stress is all-important. When bone is subjected to stress it can not withstand it fractures, either acutely or slowly as in a march fracture. But when living bone is subjected to continuing stress that is supportable it hypertrophies One example has been cited. Other common ones may be instanced in the behaviour of grafts of the Brittain type in extra-articular arthrodesis of the shoulder or the hip Both osteoporosis and hypertrophy of bone are clear examples of the state of dynamic excitability of living bone and its response to stress. Not only in growing bone but also in bone in its adult state—although in the adult it is less obvious—is this dynamic excitability retained. Bone throughout life is constantly in a state of fluctuation, of absorption and of replacement.

General reference must be made to one further function of the skeleton which is of the highest importance, namely that which it exercises as a reservoir of calcium in the body It is also a reservoir of phosphorus, but it is by no means the only or even the most important reservoir of this element. Phosphorus is present in abundance in all

tissues, mainly in cell nuclei but there is no reserve of calcium other than that in the skeleton. Normally there is a continuous loss of calcium through the kidneys. The normal level of serum calcium is 10 mgm per 100 mil of serum, and the renal threshold is 7 mgm. per 100 mil. This wastage is ordinarily made up by calcium intake from the gut, but if this be impaired or if the normal level of serum calcium be raised, say to 20 mgm per 100 mil., there is a considerable increase in the spill-over of calcium into the urine

This raising of the serum calcium level happens when the serum phosphorus level is depressed. The product of the serum calcium multiplied by the serum phosphorus ($Ca \times P = K$) is a biochemical constant which is essential to normal cellular function, particularly that of the contraction of muscle If it is not maintained the heart stops beating. Normally this constant is about 40 and the formula thus is

$$\frac{\text{Ca mgm./100 mil.}}{10} \times \frac{\text{P mgm./100 mil.}}{4} = 40$$

If the serum phosphorus is lowered, the serum calcium is raised in order to maintain this constant

$$\frac{\text{Ca mgm./100 mil.}}{20} \times \frac{\text{P mgm./100 mil.}}{2} = 40$$

This results in increased loss of calcium through the kidneys, but as this constant is essential to life and because there is no known method of administration of calcium so that a raised serum calcium level may be maintained the skeleton, the only available reservoir of calcium, is depleted.

Recent experimental work and recent observations have made it clear that the embryonic mesenchymal cells can be affected by maternal influences, and that the induced changes may be hereditarily transmitted by affected parents. It had, of course, long been known that certain skeletal abnormalities were familial, but nothing had been known of how they might be caused. Observations on the possible effect on the growing embryo of maternal rubella and the work on skeletal abnormalities induced by insulin and other noxious influences are the glimmerings of light in what was before mostly darkness, but much work remains to be done before understanding of the nature of the processes is complete or of how they may be influenced once they have been initiated. Ingalls and his co-workers have discussed these toxic influences in work to which reference was made in the section upon general orthopædics (Chapter VII).

So far as our knowledge reaches at present external stress is the only known agent whereby bone growth can be modified at will. The other conditions can be sorted into

(1) those affecting the osteoblast—osteocyte—osteoclast cycle
(2) those becoming manifest in the adult skeleton
(3) those concerned with errors of endochondral ossification
(4) those affecting the marrow constituents
(5) those induced by hormonal or nutritional influences

Most skeletal disorders can be fitted somewhere into this somewhat arbitrary classification, but the differentiation may not always be clear-cut. It may be impossible to say whether a bone dysplasia is a simple disorder of the normal process of bone formation or is in fact a tumour Two examples may be cited. The bony excrescences

at the metaphyses of the long bones in diaphysual aclasia have been called osteo- which, of course they are not and who can say when the chondroma of the ilium s the border line of disordered ossification and becomes a frank tumour growth. the behaviour of the chondrosarcoma of the ilium into which many of the osseo- lrous abnormalities of that bone develop differs in many ways from that of other nata It is a tumour but it is not a "normal" tumour There must still be some ipping in any attempt to classify skeletal abnormalities, but as our knowledge of nditions increases more and more of them can be fitted into the pattern. Much of resent and widening understanding is founded on the patient, meticulous and tened work of Sir Thomas Fairbank to whom it is not possible to pay too high e.

1 attempt at a complete survey of skeletal disorders is an undertaking too massive ese pages Rather let us try to study some of the representative types of generalized al pathology fitting them into the grouping suggested above

DISORDERS INHERENT IN THE MESENCHYME

is is a large group, and the results of inherent mesenchymal defect may become est at any age, may persist throughout life, may undergo remission at a certain age l *may subside or may become exacerbated in a quite random fashion Nothing* own of the causation of these disorders, very little of their genetic behaviour igh some information has lately become available, and nothing of their definitive ent. This is not to say that treatment is not needed—often it can be most valuable igating the complications associated with the skeletal error But in order to treat intelligently and effectively the surgeon must have some knowledge of their natural y and behaviour Is it safe to osteotomize a bone deformed by Paget s disease? d a fracture in the neck of a Paget femur be secured by internal fixation, and are any local risks attached to this operation? Is it worth while to treat fractures eogenesis imperfecta? Questions like these and they need answers, demand a edge of the behaviour of the abnormal skeleton.

ECTIONS OF THE OSTEOBLAST-OSTEOCYTE-OSTEOCLAST CYCLE

Osteogenesis Imperfecta—Fragilitas Ossium—Idiopathic Osteopsathyrosis

ause of this condition is unknown. The essential pathology is a failure of normal lastic activity The bones are slender and brittle, and may contain subperiosteal ge A characteristic feature of the condition is the deep indigo colour of the ics—quite unmistakably different from the pale blue sclerotics sometimes seen in the l infant. According to Fairbank females are affected slightly more frequently than

ree types are sometimes described—the *fetal* the *infantile* and the *adolescent* the sometimes called osteogenesis imperfecta tarda. The differentiation is, however arbitrary and is merely a measure of the degree of severity of the disorder The ial features are the same in all *In the fetal type the infant sustains many intra-* fractures is born with a chest wall which cannot withstand any stress, has a iceous skull and even if born alive soon dies. In the *infantile* type the child is t to many fractures due to slight or even trivial violence and the *adolescent* type least in degree A child of ten or so may at that time—just when she begins to be

more athletically active—sustain several fractures in rapid succession and then the tell tale blue sclerotics are noted for the first time

Four points have to be remembered The fractures heal readily in spite of the imperfect bone formation, which *is due not to absence of osteoblasts* but to failure on their part to fulfil their function Fractures should therefore be treated as in a normal patient. There is no excuse for adding the crippling disability of bone deformity to the patient s



Fig. 157 Osteogenesis imperfecta. Greatly thickened cylindrical femora with multiple fractures the thickening is not entirely due to callus. Upper ends of tibiae somewhat enlarged.
(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

already heavy burden. Further the disorder tends to remission with increase in age, and a time will come when fractures are less frequent. Lastly the disordered osteoblasts sometimes behave in an inordinately exuberant fashion in the callus of a fracture. An enormous mass of ill formed callus may appear around a fracture of the femur invade the thigh muscles, and give rise to an appearance very like that of an osteogenic sarcoma So far as I am aware, osteogenic sarcoma in association with osteogenesis imperfecta is unknown.

Osteopetrosis Albers-Schönberg s Disease; Marble Bones

In this rare disorder the failure is in the osteoclastic activity of the mesenchymal cells. When the osteocyte dies the associated bone is not removed but remains dead calcified tissue. The skeleton becomes progressively more and more dense and heavy modelling

found at the metaphyses of the long bones in diaphysial aclasis have been called osteomata, which, of course, they are not and who can say when the chondroma of the ilium crosses the border-line of disordered ossification and becomes a frank tumour growth. Even the behaviour of the chondrosarcoma of the ilium into which many of the osteochondrous abnormalities of that bone develop differs in many ways from that of other sarcomata. It is a tumour but it is not a "normal" tumour There must still be some overlapping in any attempt to classify skeletal abnormalities, but as our knowledge of the conditions increases more and more of them can be fitted into the pattern. Much of our present and widening understanding is founded on the patient, meticulous and enlightened work of Sir Thomas Fairbank to whom it is not possible to pay too high tribute

An attempt at a complete survey of skeletal disorders is an undertaking too massive for these pages. Rather let us try to study some of the representative types of generalized skeletal pathology fitting them into the grouping suggested above.

DISORDERS INHERENT IN THE MESENCHYME

This is a large group and the results of inherent mesenchymal defect may become manifest at any age, may persist throughout life, may undergo remission at a certain age period, may subside or may become exacerbated in a quite random fashion Nothing is known of the causation of these disorders, very little of their genetic behaviour although some information has lately become available, and nothing of their definitive treatment. This is not to say that treatment is not needed—often it can be most valuable in mitigating the complications associated with the skeletal error But in order to treat them intelligently and effectively the surgeon must have some knowledge of their natural history and behaviour Is it safe to osteotomize a bone deformed by Paget's disease? Should a fracture in the neck of a Paget femur be secured by internal fixation, and are there any local risks attached to this operation? Is it worth while to treat fractures in osteogenesis imperfecta? Questions like these, and they need answers, demand a knowledge of the behaviour of the abnormal skeleton.

AFFECTIONS OF THE OSTEOBLAST-OSTEOCYTE-OSTEOCLAST CYCLE

Osteogenesis Imperfecta—Fragilitas Ossium—Idiopathic Osteopsathyrosis

The cause of this condition is unknown. The essential pathology is a failure of normal osteoblastic activity The bones are slender and brittle, and may contain subperiosteal cartilage. A characteristic feature of the condition is the deep indigo colour of the sclerotics—quite unmistakably different from the pale blue sclerotics sometimes seen in the normal infant. According to Fairbank, females are affected slightly more frequently than males.

Three types are sometimes described—the *fetal* the *infantile* and the *adolescent* the last is sometimes called osteogenesis imperfecta tarda. The differentiation is, however purely arbitrary and is merely a measure of the degree of severity of the disorder The essential features are the same in all. In the *fetal* type the infant sustains many intra uterine fractures, is born with a chest wall which cannot withstand any stress, has a papyraceous skull and even if born alive soon dies. In the *infantile* type the child is subject to many fractures due to slight or even trivial violence and the *adolescent* type is the least in degree. A child of ten or so may at that time—just when she begins to be

more athletically active—sustain several fractures in rapid succession and then the tell tale blue sclerotics are noted for the first time

Four points have to be remembered. The fractures heal readily in spite of the imperfect bone formation, which is due not to absence of osteoblasts but to failure on their part to fulfil their function Fractures should therefore be treated as in a normal patient. There is no excuse for adding the crippling disability of bone deformity to the patient's



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(From An Atlas of General Affections of the Skeleton by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

already heavy burden. Further the disorder tends to remission with increase in age and a time will come when fractures are less frequent. Lastly the disordered osteoblasts sometimes behave in an inordinately exuberant fashion in the callus of a fracture. An enormous mass of ill formed callus may appear around a fracture of the femur invade the thigh muscles, and give rise to an appearance very like that of an osteogenic sarcoma So far as I am aware, osteogenic sarcoma in association with osteogenesis imperfecta is unknown.

Osteopetrosis Albers-Schönberg's Disease Marble Bones

In this rare disorder the failure is in the osteoclastic activity of the mesenchymal cells When the osteocyte dies the associated bone is not removed but remains dead calcified tissue The skeleton becomes progressively more and more dense and heavy modelling

is imperfect, and the medulla of the bone is more and more encroached upon. This accounts for one of the characteristic complications—the one which is usually the cause of death—namely severe and intractible aplastic anæmia. The base of the skull becomes a mass of heavy petrotic bone, the foramina are narrowed, and optic atrophy and deafness are not uncommon sequelæ. Although the bones are abnormally dense and hard, they are also brittle, and pathological fractures occur easily The shape of the fracture is often characteristically transverse and union is slow



FIG. 158 Osteopoikilosis. The knee joints show alternate dark and light transverse bands with greatest density at the ends of the metaphyses suggesting that the tendency to formation of osteopetrotic bone is becoming more marked. The bands are broader and less sharply defined than the so-called "lines of arrested growth.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone, Ltd.)

The condition may progress steadily may undergo temporary remission so that throughout the skeleton bands of normal bone may be seen in the petrotic bone or may abate completely Nothing is known of its cause, nor is there any means of influencing its course. There is a distinct familial tendency and parental consanguinity is a factor in the more severe malignant type of the disorder It was first described by Albers-Schönberg in 1904

Melorrheostosis

This is a rare type of localized petrosis of the skeleton which may affect only one limb or even only one bone. The lower limbs are more frequently involved than the upper Normally not the whole of the metaphysis is affected but only one aspect, so that the appearance has been likened to that of poured candle grease spread down the bone—the name of the condition derivatively likens it to running honey The differentiation from osteopetrosis is easy—in that condition every bone in the skeleton is affected in some degree as distinct from the characteristic limitation of the change in melorrheostosis to one bone, or at most one limb Further the lesions are painful and may be

associated with scleroderma or a soft tissue fibrosis, which osteopetrosis never is The pain may be such as to make surgical excision of the lesion necessary This cures the symptoms

Osteopoikilosis

In this condition punctate spots of dense petrotic bone are randomly distributed throughout the cancellous bone of the epiphysial region of the metaphyses of long bones and in the pelvis, but almost never in the skull and never in the ribs or the vertebræ



FIG. 159 Osteopetrosis. Pelvis showing dense bone in and on the surface of the right ischium and pubis. *(From An Atlas of General Affections of the Skeleton by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)*

The condition is pathologically unimportant and is usually discovered by chance. It never causes symptoms and when the nature of the change in the bony architecture has been recognized it can be disregarded. Males are much more commonly affected than females.

Arachnodactyly

This peculiar condition can probably be classified with those described above. It is essentially a disorder of the mesenchymal bone growth, but its effects are distributed in a characteristic fashion, impinging on the short long bones of the hands and feet. These are overlong and slender in structure—hence the name of the condition. There is also however evidence of generalized mesenchymal disorder The subjects are above normal height, are slenderly built and are poorly muscled. The deformity is most evident in the hands and feet, but all four limbs are disproportionately long. The relative lengthening of the long bones increases progressively from the hip or shoulder to the digits, and the most striking clinical feature is usually the abnormal length of the feet. The patients



FIG. 160. Osteopoikilosis. Wrists and hands showing typical dense spots, thickly distributed in the lower epiphyses of the radius and ulna, and in the carpal bones. Note that the spots are seen also at both ends of the metacarpals, and not only in the old epiphyses.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)



FIG. 161. Arachnodactyly. Feet showing excessive length and, in the left foot, the calcaneo-cavus deformity can be seen.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

afflicted with this mesenchymal disorder are never robust and not infrequently die at an early age from some intercurrent ailment.

AFFECTIONS OF THE OSTEOBLAST-OSTEOCYTE-OSTEOCLAST CYCLE IN LATER LIFE

These cover a vast field of skeletal pathology the causation of most of which is obscure. It is true that some of the disorders may be simulated in some form by a known cause of hormonal upset (q v) namely hyperparathyroidism, but this condition is not common, whereas the skeletal changes which might be associated with it are amongst the commonest of bone disorders. Most often there is not any evidence of parathyroid pathology—the effects of this will be discussed later—the behaviour of the condition is quite random, and the cause is quite unknown. These conditions will be arbitrarily classified under the heading of fibrous dysplasias because broadly the behaviour of all of them is basically similar although different in detail.



Fig. 162. Osteitis Deformans. Right arm showing honey combed type of disease in humerus and ulna and some atypical change in the radius.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

Paget s Disease Osteitis Deformans

This is the commonest of bone disorders. It is due to a breakdown of the osteoblast-osteocyte-osteoclast cycle, but is peculiar in that this process has always worked with apparent normality before the evident onset of the disorder The condition was first described by Czerny in 1873 but Paget s paper in 1877 forever linked his name with the disorder which Czerny called *osteitis deformans*

The characteristic feature is that of radical change in the bony architecture. Normal lamellar bone is replaced by a mixture of spongy bone and fibrous matrix, the whole bone is thickened and may actually grow in length—the only example of growth in length in a bone in which the epiphyses are closed—and the differentiation between cortex and medulla disappears. Radiologically macroscopically and microscopically the structure of the bone becomes homogenous. Osteoclasts are prominent and numerous but not in such collections as to be said to form osteoclastomata the activity of the osteoblasts is evidenced by the raising of the level of the serum alkaline phosphatase to three or more times its normal level.

The impact on the skeleton is completely random. Only one bone may be affected, and if it is a single bone it is most frequently the tibia. Only one portion of the tibia may be affected, and it is not uncommon to see characteristic Paget change localized in the upper half of one tibia only the rest of the skeleton being completely normal. On the other hand, there is in the Museum of the Royal College of Surgeons of Edinburgh the skeleton of a man with generalized Paget s disease in which all the bones are grossly affected except for the right humerus and the left ulna, which are macroscopically normal.

The most usual reason for the patient seeking advice is deformity of the affected limb—usually bowing of the affected tibia. Pain is not a common early feature

Pathology Because of the alteration in bony structure, the bones become softened and labile, and therefore tend to bend under stress—hence the name osteitis deformans. The bones may also fracture and this they do in two ways. Firstly there may be an ordinary *pathological fracture of the shaft of the long bone or of the neck of the femur* Secondly there may be a series of fractures along the convex aspect of the cortex of a bowed tibia. A series of serrated transverse fractures through this convex aspect, but extending only about a third of the way across the bone, is very characteristic. The frank pathological fractures of Paget's disease have inherent and important characteristics. Firstly they are almost always transverse in shape—most fractures of the long bones show at least some degree of obliquity but a Paget bone breaks like a piece of chalk. Secondly they heal but they heal slowly taking at least as long again to unite as does normal bone. The affected bone is hyperæmic and the limb is therefore often warm to the touch and may be painful. The further effects of this hyperæmia of the bone are elaborated later

Complications

Deformity The reason for deformity of the bones in Paget's disease has been discussed. It is seldom necessary to carry out any corrective procedure to combat this deformity but if for any reason it should be necessary it may be undertaken with the knowledge that a Paget bone will heal, although more slowly than a normal bone. Deformity however seldom gives rise to therapeutic difficulty

Pain. Pain in a Paget bone is due to two causes (1) the tension within the hyperæmic bone (2) the multiple spontaneous cracks in the convex surface reference to which has already been made. It is important to distinguish which of these two causes is responsible for the pain. If it be the occurrence of multiple fractures, immobilization of the limb by a suitable splint, such as a plaster cast, may be all that is needed. If the pain is the result of hyperæmic tension, then relief is sometimes afforded by a linear osteotomy—a section out of the cortex of the bone of a long sliver some 30 cm. long and about 1 mm. wide.

Pathological Fracture. Pathological fractures in Paget's disease heal under a régime of ordinary fracture treatment. There is no problem so far as external splinting is concerned and the usual lines of fracture treatment may be followed. Internal splinting raises one or two special problems. There is a recent fashion for fixation of the shaft of the long bones by the introduction of an intramedullary nail. It must be remembered that in Paget's disease there may be no medulla, and if a longitudinal nail is to be used a medulla may have to be previously reamed out of the disordered bone. If this is done with care, intramedullary nailing can be a very useful method of dealing with fracture of the shaft of a long bone in Paget's disease. Another condition in which internal fixation would appear to be ideal treatment, but in which a special difficulty arises, is that of fracture of the neck of the femur in a Paget bone. The ordinary routine of trifin nailing is *satisfactory* but *it must be remembered* that the neck of the femur in Paget's disease does not contain cancellous bone as does the "normal" fractured neck it is composed of a mixture of spongy bone and fibrous tissue. It therefore does not accept a nail as easily as does the neck of a femur of normal texture, and unless the nail is introduced with care there is a risk that the abnormal bone may be disrupted. A fracture of the neck

of the femur in Paget's disease may be treated by internal fixation but the internal fixation must be carried out with particular care and gentleness.

Sarcoma. It is not surprising that when the normal behaviour of the bony structure has already been so grossly upset, malignant change may supervene. Sarcomatous degeneration in Paget's disease is not uncommon, but it occurs particularly in three sites. It is common in the skull it is common in the pelvis and it happens not infrequently in the neighbourhood of a fracture. It is, of course, open to question whether the fracture was due simply to the Paget change in the bone, or was an early manifestation of the sarcomatous degeneration.



FIG. 163 Chondroma of ilium. Pelvis and hips showing irregular increased density of left side of pelvis with signs of sarcomatous growth in the ilium.

(From An Atlas of General Affections of the Skeleton by Sir Thomas Fairbank, E. & S. Livingstone Ltd)

Cardiovascular A little recognized complication of this disorder is that of a consequent disturbance of the cardiovascular mechanism. The blood flow throughout the bones is so enormously increased that the result is almost comparable with that of an arteriovenous shunt, such as occurs in a frank arteriovenous aneurism. Some of these patients therefore may die of left ventricular failure.

Fibrocystic Disease of the Bone

This disorder may be monostotic or polyostotic, and in one peculiar type is associated with sexual precocity and pigmentation of the skin. The long bones are affected by this error most commonly the proximal long bones, and the upper end of the femur in particular The changes are similar to those in hyperparathyroidism but may be manifest without any parathyroid tumour or over-activity They are of two types—either there is a fibrous coarsening of the bone trabeculæ similar to that in Paget's disease or a cystic area or areas may develop in the bone. These cysts may contain a clear brownish-yellow fluid They are benign lesions with a strong tendency to spontaneous healing if they are traumatized A pathological fracture through such a cyst heals readily under

treatment, and as it heals the cyst heals. The surgical treatment consists of opening the cyst, clearing out the contents, and inserting a few chips of cancellous bone. The cystic area consolidates rapidly in response to this. They are painless lesions and are discovered usually either incidentally or when they undergo fracture. They are to be distinguished from osteoclastomata, which is the lesion they clinically most nearly resemble, for the treatment and prognosis are quite different.

Fibrous Cysts	Osteoclastomata
Commonly seen at age 5–15 years.	Rarely seen until over 20 years.
Confined to the metaphysis whether the epiphysis is open or not.	Cross the epiphysial line and invade the epiphysis.
More common in males.	More common in females.
Most common site upper femur and upper humerus.	Most common site lower femur lower radius and upper tibia.
Does not expand the bone.	*May expand the bone.*
Radio-resistant.	Radio-sensitive.
May occasionally be associated with skeletal or sexual precocity	Never any general effects.



FIG. 164 Bone cyst Left humerus showing (*left*) cystic changes at upper end of shaft, and (*right*) the same nearly six years later

(*From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E & S. Livingstone Ltd*)

Albright's Syndrome

This is a peculiar polyostotic type of fibrous dysplasia, confined to one half of the skeleton, although not necessarily affecting the whole of that half and associated with patchy skin pigmentation and sexual and skeletal precocity The children tend to grow rapidly and are large for their ages, but the early closure of the epiphysis associated with precocious skeletal maturation means that the permanent height is less than average.

EPIPHYSIAL DISORDERS

Achondroplasia

This is dwarfing due to failure of growth of the epiphyses of the long bones. The skull, in which the ossification is membranous, is not affected and the head and face are

normal The spine is little affected as growth of the vertebral column is mainly due to appositional endochondral ossification, the ring epiphyses contributing very little to the ultimate size of the vertebral bodies though the pelvis is smaller than normal it is not grossly so

All the long bones are usually affected (although exceptionally the change may be confined to one pair of limbs or even one bone) and the result is a person with a more or



FIG 165 Photograph shows the typical features of achondroplasia.
(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd)

less normal head and trunk, short limbs and short stubby fingers. The cause is unknown, but the defect is in the ovum and the changes are manifest in pre-natal life General health and intellect are unaffected—indeed they are jolly little people, were the court dwarfs of the Middle Ages and are the circus clowns of today Worse fates can befall a man than achondroplasia.

Metaphysial Aclasis: Diaphysial Aclasis Multiple Exostoses

This is a disorder of endochondral ossification which manifests itself at the epiphysial plates. Islets of cartilage cells become displaced or left outside the bone as it grows ossify in the surrounding soft tissue and become exostoses. These exostoses are finger like processes of bone, projecting from near the epiphysis and pointing towards the

centre of the metaphysis, covered by a cap of cartilage From this cap of cartilage they grow until the associated epiphysis fuses and then growth ceases. These exostoses may be few in number—even single—or they may be very numerous affecting all the epiphyses. They affect mainly the ends of the long bones, particularly the end at which growth is greater They may affect the metacarpals, metatarsals or phalanges, but the more usual



FIG. 166. Achondroplasia. Lower limbs showing the typical short stout bones with splaying at the extremities, irregularity of the ends of the metaphyses, and characteristic position of the ossific centres. Note the length of the fibula the head is abnormally high in both legs at the ankle joint the fibula reaches rather lower than usual.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

form in the small bones is that which is next described, namely *dyschondroplasia* Very rarely they may occur in the spine and give rise to a neurological lesion.

In addition to the deformity of the bone due to the exostoses there is a failure of the normal modelling or tubulation of the bone. The end of the metaphysis as it grows is not moulded into the normal cone or trumpet shape but remains cylindrical. This is a very characteristic feature of the disorder Sometimes, but by no means always, there is dwarfing, or there may be inequality of the lengths of the limbs, but the more affected limb is not always the shorter

Clinical Features and Complications. In the main these lesions are essentially benign and treatment is called for only on account of their mechanical effects. A large exostosis may interfere with the lacing of a boot or with the wrist strap of a watch, or an exostosis at the knee may cause inconvenience by knocking against the other knee. If these effects cause trouble the exostosis should be removed. Very occasionally and usually in later life, say around the age of 50, an exostosis may begin to grow rapidly. This is usually a sign that malignant change has supervened, and that the disordered growth has become a



FIG. 167 Metaphysical Aclasis. Right knee. The lower femoral metaphyses show irregular enlargement, with loss of the normal trumpet-shape, and with exostoses projecting from its surface. Note the characteristic shape of the exostoses which are inclined towards the centre of the shaft. An exostosis on the inner aspect of the tibial head appears to have been fractured.
(From An Atlas of General Affections of the Skeleton by Sir Thomas Fairbank, E. & S. Livingstone Ltd.)

neoplasm—a chondrosarcoma. Sudden progressive enlargement of any exostosis in metaphysial aclasis should be viewed with gravest suspicion.

Dyschondroplasia. Ollier's Disease. Multiple Enchondromata

In this developmental error cartilage rests are displaced into and fail to ossify within the shafts of the long bones, especially the shorter long bones and more particularly in the hands than in the feet. It was first described by Ollier of Lyons in 1900. It has been suggested that it is a variant of metaphysial aclasis, but the features of the two conditions are quite distinct.

The enchondromata tend to be predominantly unilateral. They may rarely be single

I have treated a patient who was a shorthand typist and a golfer of county class in whom the first sign of trouble was when she sustained a pathological fracture through a terminal phalanx at the age of 45 The basic pathology was an enchondroma and it was the only one. Conversely there may be so many enchondromata throughout the metacarpals and phalanges of one hand that the hand is crippled and useless, while there are only one or two scattered lesions in the other hand.

The lesions occur also at the ends of the metaphyses of the long bones, the region of the knee joint and the lower end of the radius and ulna being particularly common sites. Except in the phalanges the lesions do not grow and do not expand the bone but in the hand they may as has already been said, cause crippling deformities. There is usually dwarfing of the affected limb.



FIG. 168 Multiple enchondromata (Ollier). Right forearm and hand. The metacarpals and phalanges show many enchondromata. Those in the digits have proliferated to such an extent that the hand is hopelessly crippled. The carpus, as usual, is free from cartilaginous masses The lower end of the radius shows fairly typical appearance several dense spots are seen The ulna is surprisingly normal both in length and texture, but there is a cartilage mass in the upper part of the lower third

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E & S Livingstone Ltd)

The condition is benign and the treatment consists of evacuation of the endosteal cartilage by osteotomy The bone heals readily but healing may and usually should be accelerated by packing the cavity with bone chips. In the fingers it is sometimes better to attempt to restore the shape of the digit by clearing out the cartilage and compressing the ballooned thinned cortex by osteoclasis. In lesions of the ends of the larger long bones osteotomy is not needed unless the lesion be single and the diagnosis therefore not completely certain. The diagnostic biopsy will usually bring about obliteration of the lesion as well as establishing the diagnosis.

Chondro-osteo-dystrophy (Morquio-Brailsford)

In 1929 Morquio and Brailsford independently described and classified this error of skeletal growth which is now associated with their names. It had previously been described by several writers and thought to be an atypical achondroplasia, but though the child is dwarfed the dwarfing is quite different from that of the other condition. The achondroplasic is a dwarf because the long bones are shortened in the child with chondro-osteo-dystrophy the dwarfism is due mainly to lack of vertical growth of the spine, and kyphosis. The radiographic appearances of the spine are typical. The vertebral

bodies are shallow and characteristically elongated and tongue-shaped and the intervertebral spaces are markedly widened. There are usually irregularities of the long bone epiphyses and the child is flat footed. The acetabula are poorly formed the capital epiphyses of the femora are flattened, fragmented and commonly rectangular in shape, and these epiphyseal abnormalities and those at other bone ends cause bone deformities and shortening of the limb

Familial influence is strong though there may not be evidence of direct heredity In one family known to me the incidence is as shown

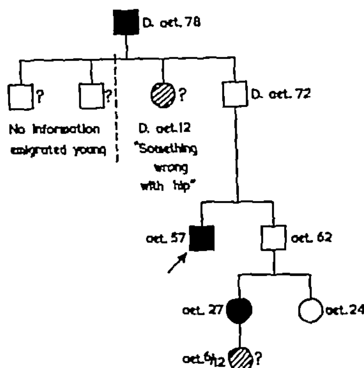


FIG. 169

My patient is indicated with the arrow—he came under care at 56 because of painful hips. He had all the stigmata of the disorder His father was unaffected—he is now dead and the information about his siblings is incomplete—but it is known that his grand father "had something wrong with his hips." He was otherwise healthy and died in old age. The patient s brother is not affected one niece is, and her baby is still too young for precise diagnosis. The cause of the condition is quite unknown and treatment is symptomatic—usually the alleviation of joint pain due to secondary arthritic changes. This family described was robust, although Fairbank says the patients are characteristically feeble

Gargoylism. In this type of chondro-osteo-dystrophy there is in addition to the dwarfism a heavy ugly facies, almost always a high degree of mental deficiency distension of the abdomen and enlargement of the liver and spleen. This and the corneal opacities have led some to suggest that this condition should be classified with the lipoidoses. The

radiographic appearances of the skull, the spine, and the hips show changes similar to but not identical with those of the previous dystrophy (see Fairbank 1951) The children mercifully almost all die young



FIG. 170. Chondro-osteo-dystrophy Spine, showing shape of the bodies with the central "tongue" in front. The second lumbar body is small and displaced backwards The discs are unusually deep.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd)



FIG. 171 Chondro-osteo-dystrophy Radiograph of the spine shows an angular deformity with the apex at the second lumbar vertebra, the body of which is small, beaked and displaced little backward. The other vertebral bodies are biconvex and not flattened.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E. & S. Livingstone Ltd)

Disorders of the Lipoid Constituents

These are probably not primarily skeletal disorders for most show changes in other organs such as the spleen, the liver or the conjunctiva, but as the bone changes are profound they must be considered. The conditions are relatively rare and for this reason will not be described in detail They have the common features that in the skeleton pathological lesions of an osteolytic nature appear always containing granulomatous material usually invaded by eosinophils and often with a high lipoid content.

The several names given to the various manifestations of this protean group of disorders are

(1) Lipoid granulomatosis.
(2) Eosinophilic granuloma.
(3) Hand Schüller-Christian Disease
(4) Niemann Pick's Disease
(5) Gaucher's Disease or Splenomegaly

A full account of these rare conditions will be found in Fairbank's "Atlas of General Affections of the Skeleton," and in Snapper's "Medical Clinics on Bone Diseases" and in the paper published by Jaffe and Lichtenstein in 1940 and 1944

DISORDERS OF ENDOCRINE ORIGIN

Hyperparathyroidism Osteitis Fibrosa Generalisata von Recklinghausen's Disease

This condition was first described by von Recklinghausen in 1891 and is the earliest recorded example of precise linking of skeletal abnormality with an endocrine disturbance he described the post mortem findings in a patient with widespread skeletal changes and an oval tumour in the back of the thyroid gland.

The essential pathology of the condition is that as a result of the parathyroid over activity the serum phosphorus is lowered. The serum calcium is accordingly raised perhaps up to 25–30 mgm. per 100 mil., there is an increased loss of calcium in the urine and the skeleton is depleted of calcium. The osteoporosis affects the whole skeleton. The bones become soft and liable to pathological fracture and may as in von Recklinghausen's original case, show cysts containing brown or reddish-grey gelatinous material and resembling osteoclastomata

Pain, apart from pathological fracture, is an early feature and in the untreated case, pain and crippling deformities gradually progress until the patient dies. In about one half of the cases there are renal changes due to the increased excretion of calcium in the urine, and bilateral renal lithiasis should always be regarded with suspicion. As often as not it is a manifestation of hyperparathyroidism, and it may be the earliest sign of the condition. Occasionally the calcification occurs within the substance of the kidney in the renal tubules and may give rise to renal failure without clinically or radiologically evident nephrolithiasis. In either event pyelitis or pyelonephritis is a common complication.

A hyperfunctioning adenoma, composed of large cells with hyperchromatic nuclei, is found in one or occasionally more than one of the parathyroid glands. It may not be possible to palpate it, but the clinical features of the skeletal changes, the urinary lithiasis or other evidence of renal damage, and the characteristic lowering of the serum phosphorus and raising of the serum calcium prove its presence. Aird has recently described a method whereby an inconspicuous parathyroid adenoma may be located. The neck is opened and the inferior thyroid arteries are defined The artery on the side of the adenoma is larger than its fellow If further proof be needed an arteriogram may help Removal of the adenoma by operation leads to an early and gratifying reversal of the changes in the blood chemistry and the skeleton. Failure to respond to operation usually indicates the presence of a second adenoma or that the first was malignant and had metastasized

The differential diagnosis should not cause difficulty The clinical picture and the biochemical findings are characteristic. In Paget's disease the changes are never generalized though they may be widespread, and in the skull there is thickening of the vault which is not seen in hyperparathyroidism. The serum calcium is normal, as also is the phosphorus. Finally the age incidence differs, Paget's disease occurring in the later age groups. Polyostotic fibrous dysplasia is not generalized and there may be associated skin and sexual changes, never seen in hyperparathyroidism Differentiation from generalized carcinomatosis may cause difficulty and in view of the rapid increase of knowledge about the hormonal control of certain cancers is of growing importance In multiple myelomatosis the serum phosphorus is normal and there is Bence Jones protein in the urine. The diagnosis is clinched by sternal marrow puncture. Bilateral renal lithiasis is always strongly suggestive of hyperparathyroidism.

Pituitary Dystrophies

The effects upon the skeleton of pituitary dysfunction are varied and depend upon three factors

(1) whether the error is pituitary over-activity—eosinophil adenoma, or under activity—basophil adenoma.

(2) whether the skeleton is mature or immature when the pituitary dysfunction begins

(3) whether the main secondary effect is produced through the gonadotrophic or the adreno-corticotrophic hormone.

Moreover the types may be mixed, and a very confusing picture indeed may result. Some examples are cited, but this cannot be regarded as a complete survey

If the hyperpituitarism develops before the epiphyses are fused there is overgrowth of the skeleton and the result is a pituitary giant. The onset of the disorder is usually about puberty When skeletal growth ceases the skull may continue to grow and the condition known as acromegaly is seen—the same condition as is produced when the hyperpituitarism develops after growth has ceased. But if the hyperpituitarism is associated with over-activity of the gonadotrophic hormone the epiphyses fuse early and the overall height of the patient is less than normal—one form of pituitary dwarfism. In addition there is hirsutism and precocious or exaggerated sexual development, and, in women, a tendency towards virilism. Pituitary giants have poor resistance to infection and often die young, frequently of tuberculosis

Acromegaly This condition is the result of pituitary over-action due to an eosinophil adenoma after the skeleton has matured, or develops in the later stages of pituitary gigantism. The bones most affected are those of the skull, the mandible, the hands and the feet, but the clavicles may also be enlarged. Headaches may be a feature, and neuropathies of the cranial nerves, particularly the oculomotor but often the first abnormality that the patient notices is that he or she (for both sexes are affected) needs larger hats, gloves and shoes. The enlargement of the mandible leads to protrusion of the lower jaw so that the lower teeth project over the upper and normal occlusion is lost. In later stages other endocrines are often disturbed and there may be sexual changes—either hypertrophy or atrophy with impotence and even a tendency towards feminism in males—amenorrhoea, diabetes insipidus, and usually depression of the basal metabolic rate. Later there may be skeletal changes due to and characteristic of parathyroid over action. The most marked radiological changes are in the skull and facial bones, particularly the lower jaw which is grossly enlarged, but there is also hypertrophy of the zygomatic arches and the supra-orbital ridges, and the frontal sinuses are increased in size. There may be visceral enlargement, both of the stomach and gut and of the solid viscera

The sella turcica usually but not always shows some deformity most often irregular enlargement. Osteoarthritis is common There are changes in the vertebræ, notably the deposition of irregularly formed new bone on the surfaces of the vertebral bodies so that the antero-posterior diameter is increased, but the spinal canal is seldom encroached upon.

The rate of progress of the disorder is very variable and it may remain stationary for years. Death is from intercurrent infection, to which these patients are susceptible, or from

complications associated with one or other of the secondary effects, but many live for about the normal span. The disorder may however become active after many years of apparent quiescence.

Hypopituitarism Dystrophia Adiposo-genitalis Fröhlich's Syndrome

This is the result of under-action of the whole pituitary usually due to pressure on the gland by a basophil adenoma or to a tumour such as a cranio-pharyngioma which encroaches upon the sella turcica, as Fröhlich described in his original case in 1901 The classical Fröhlich syndrome is rare, but the effects of hypopituitarism on the physical make-up and on the skeleton due to associated hypogonadism are common. The condition has been given the name of adipose gynandrism The patients are usually of average height, but are fat and show sexual under-development The fat is distributed particularly around the lower trunk, the breasts, the thighs and the arms—not the legs or forearms. The facies is often heavy and unintelligent though the intellect is usually not impaired. The most important effect upon the skeleton is the delay of epiphysial fusion which often manifests itself in the slipping of the upper femoral epiphysis (*see* p 125)

Cushing's Syndrome Pituitary Basophilism

When Cushing first described this syndrome in 1932 he thought it was invariably due to a basophil adenoma of the pituitary but study of the condition has made it clear that many of the effects were due to considerable over-action of the adreno-corticotrophic hormone and that it may be caused by a tumour of the adrenal cortex itself It affects mainly women and is characterized by the rapid onset of a coarse obesity hypertrichosis, glycosuria and amenorrhœa.

The effects on the skeleton are due to over-secretion of gluco-corticoids (11-oxy steroids) and of androgen hormone (the N hormone of Albright). These together lead to premature fusion of epiphyses, osteoporosis, and delay in the healing of fractures. The condition is progressive and the patient usually dies within a few years.

Pituitary Dwarfism; Ateleiosis. This condition is due to underaction of the pituitary affecting mainly the growth hormone and showing little in the way of side effects, except, in one type, on sexual function The condition may occur without or with normal sexual development—in both the skeletal changes are similar and consist of a general symmetrical failure of skeletal growth, which may however be normal for two or three years before the onset of the condition The sexual type tends more to be congenital and these patients are the more robust—they are the circus midgets, and often live to old age The asexual type tend to die young.

Thyroid, Gonads and Adrenals. The effect upon the skeleton of congenital deficiency of thyroid secretion is, as might be expected, generalized failure of growth with delayed fusion of the epiphyses. Besides showing the other effects of hyperthyroidism such as mental dullness, sexual retardation and lowering of the basal metabolic rate, the patients are dwarfed, seldom growing to much over four feet in height. Closure of the fontanelles is delayed, the skull sutures remain open long after they should have closed, [illegible] epiphyses are fragmented and distorted. Even under efficient treatment [illegible] changes may be irreversible.

The most important skeletal change in hyperthyroidism, a condition [illegible] occurs before the skeleton is mature, is that of generalized osteoporosis [illegible]

seen in young women. Any difficulty in differential diagnosis from hyperparathyroidism, which the condition most nearly resembles, is resolved by observation of the other unmistakable signs of hyperthyroidism.

The complex effects of disorders of gonadal or adreno-cortical secretion have already been referred to in connection with the pituitary disorders. In general over-action of either tends to produce accelerated skeletal growth and early maturation of the skeleton. As a result of the early fusion of the epiphyses the adult stature tends to be less than normal in spite of the initial rapid growth. Under-action produces delay in epiphysial fusion and may lead to epiphysial slipping, like that of the capital epiphysis of the femur in adipose gynandrism. In rare cases it may lead to an increase in stature, as in eunuchoid gigantism—a condition resembling pituitary gigantism, but usually manifesting itself later in life, always associated with marked sexual deficiency seldom with gross skeletal overgrowth, and never with acromegaly

NUTRITIONAL FACTORS

Infantile Scurvy

Scurvy is a rare condition now In this country it is now seen only in infancy usually around the age of one year It is due to a deficiency of Vitamin C in the diet. The effect on the skeleton is three-fold osteoporosis failure of epiphysial ossification and subperiosteal hæmorrhages. The hæmorrhages begin at the epiphysial line the one at which growth is greater and spread along the metaphyses of the long bones, notably the femur the humerus and the tibia. There may be associated epiphysial separation. A characteristic clinical feature is the extreme tenderness of the affected limb—the child's reaction makes it evident that even to touch the limb causes agony The cortex of the bone is thinned and the whole bone is osteoporotic. There is a tendency to spontaneous fracture which would be more common were it not that the tenderness of the bone makes the child keep the limb still The subperiosteal hæmorrhages indeed originate in cracks in the thinned cortex. Under efficient treatment with Vitamin C or ascorbic acid 300 mgm. in the day the changes are rapidly reversed, the hæmatomata are absorbed, and normal calcification of the skeleton and normal epiphysial growth are re-established. The condition has been confused with rickets with which it may well be combined but Glisson pointed out over three centuries ago that they are separate entities.

Rickets

This is a metabolic disorder due to lack of Vitamin D in the diet and is manifested in defective calcification of growing bone and osteoporosis of formed bone The former is the more characteristic of the errors. The epiphysial lines are wide and ill-defined, the osteoid fails to calcify and hence to ossify and the bones are undergrown, soft and liable to deformity due to bending. The head is relatively large with frontal bossing, and the primary cartilaginous joints of the costochondral junctions are prominent, the series of lumps on the chest wall going by the name of the "rickety rosary" The joint ligaments in the limbs are lax and thus allows of further deformity in addition to that caused by the bending of the softened bones. If the child is of an age to sit or stand there is a kyphotic deformity of the spine, even to reversal of the normal lumbar lordosis.

Under efficient treatment with Vitamin D or radioactivated ergosterol the skeletal

errors are usually rapidly reversed, but occasionally the condition of vitamin resistant rickets may be encountered when huge doses must be used. Up to one and one-half million units of Vitamin D in the day may be needed to bring the condition under control. Although vitamin-resistant patients have an increased tolerance to Vitamin D these high



FIG. 172. Scurvy. Left leg showing typical appearance of subperiosteal hæmatoma of the femoral shaft in which ossification is well advanced.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank. E. & S. Livingstone Ltd.)



FIG. 173. Rickets. Wrist and hand showing rachitic changes, "cupping" of the radius and ulna and poor calcification of all the bones.

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank. E. & S. Livingstone Ltd.)

doses cause a risk of hypervitaminosis D one of the manifestations of which is otosclerosis.

Cœliac Rickets. This condition occurs in association with and is caused by difficulty in the absorption of fats due to cœliac disease. The diagnosis rests upon the characteristic findings on examination of the stool.

Renal Rickets. Renal Dwarfism. Renal Infantilism. Renal Osteodystrophy. In this condition the rachitic changes are due to errors in the phosphorus-calcium metabolism due to tubular disease in the kidneys. The skeletal changes are similar to those in true rickets, and epiphysial separation is common. Brailsford pointed out in 1933 that the urine of every patient with adolescent coxa vara should be carefully examined. Urinary

changes—blood, albumin, casts, and calculi—establish the diagnosis and differentiate the condition from delayed or vitamin resistant rickets

Osteomalacia. This condition is the counterpart in adults of rickets in children and is due to similar causes. It is rarely seen in this country but it can occur as a result of gross dietetic insufficiency resulting in deficient intake of calcium and Vitamin D associated with lack of exposure to sunlight. Women are affected more than men, because of the greater demands that female metabolism makes upon the body's store of calcium, and pregnancy may be the precipitating factor. Men, however may be affected. Spontaneous fractures are common, and may be caused by the tetany which the condition not infrequently induces. The treatment consists of correcting the dietetic error



FIG. 174 Renal rickets. Left wrist showing rachitic changes in radius and ulna

(From "An Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank, E & S Livingstone Ltd)

Senile Osteoporosis. As age increases the osteoblastic activity of the mesenchyme is diminished and the skeleton becomes increasingly porotic. The fact that the condition is more common in old women suggests that diminished physical activity may be an ætiological factor. Fracture of the neck of the femur is common, but any fracture of a long bone may result from slight violence. The changes are most marked in the spine and multiple compression fractures of the vertebral bodies are the commonest complications of the condition.

For further information about the very complex subject with which this chapter deals the excellent "Atlas of General Affections of the Skeleton" by Sir Thomas Fairbank should be consulted. This book not only gives a very full and clear account of skeletal disorders but also contains an incomparable bibliography

CHAPTER IX

ARTHROSTEAL TUBERCULOSIS

NORMAN CAPENER

INTRODUCTION

IT must be recognized that tuberculosis is a general constitutional disease, even though the main or only local evidence of it is to be found in skeletal tissues. In the latter it is a hæmatogenous infection carried from focal infection which commonly arises in the lungs or upper air passages, the alimentary tract or from skin infection in workers particularly exposed to tuberculous material, for example, butchers and farm workers. While there are a number of different types of tubercle bacillus according to the animal of origin, by far the most important are the human and bovine; of these the human infection is dominant. In the past there was a relative increase in the proportion of bovine infections in early childhood, but the absolute proportion in Great Britain was not more than 30 per cent and this only for a very small group, namely infants with spinal lesions. In individuals over sixteen years the percentage of bovine infection was lower. The incidence of bone and joint disease has in recent years shown a marked change, and now in Great Britain it is uncommon in young children. Accordingly there is a relatively greater incidence between the ages of twenty and thirty.

Sites of Involvement. In order of frequency the disease involves the spine, the hip, the knee and other joints. The most common focus is that which appears in the vascular growing areas of bone, the epiphyses, and metaphyses. The proximity of the vascular supply of these structures to that of the synovial membrane of neighbouring joints accounts for the frequency with which the joints are also involved; thus the term *arthrosteal tuberculosis*. The tuberculous focus in bone arises as an embolism of the finer arterioles with the formation of "tubercles" which coalesce to form the characteristic granulation tissue. With endarteritis there occurs some degree of vascular obstruction and avascularity, and the gradual extension of the tuberculous granulation tissue into the devitalized parts.

The order in which tuberculosis develops is as follows—invasion causing the primary focus, particularly the respiratory passages; lymphatic spread to neighbouring lymph nodes, hæmatogenous spread to bones and joints and to other tissues (notably the kidneys) and from these secondary foci it is possible for further lesions to occur in areas elsewhere. In the extreme case, either from primary or secondary lesions, spread may again occur through the blood stream and be manifest as generalized miliary tuberculosis or meningitis. Glandular tuberculosis which was formerly so common a form of the general disease in childhood, particularly affecting the cervical lymph nodes, has become less common with improvements in child hygiene as well as in the production of milk.

The involvement of such tissues as the lungs, the kidneys and meninges seriously affects the prognosis, but there are other complications which have special significance

in the skeletal system. The enlargement of the focus and its caseation leads to the formation of abscesses which differ from those of pyogenic origin in having fewer signs of inflammation and therefore are often called *cold abscesses*. These abscesses are a further stage in the breakdown of the necrotic products of caseation and may extend far from the primary focus along fascial planes and appear as painless swellings on the surface of the body; unless carefully treated they may rupture and produce sinuses, which may be followed by secondary infection with pyogenic organisms. Such mixed infection aggravates the virulence of the disease and adversely affects its prognosis. Abscess formation may in certain positions lead to special complications, particularly if the abscess ruptures into a serous cavity, such as the pleura, or if it extends into the spinal canal and there causes pressure upon the spinal cord leading to paraplegia.

The Vascular Factor in Tuberculous Lesions

The hyperæmia which develops as a response to the focal infection in tuberculosis is well seen in radiographs of early bone lesions, as an area of reduced density (osteoporosis).

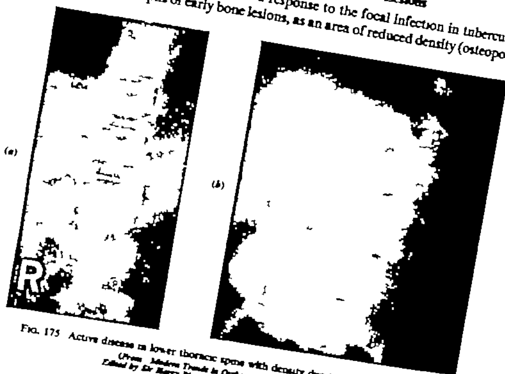
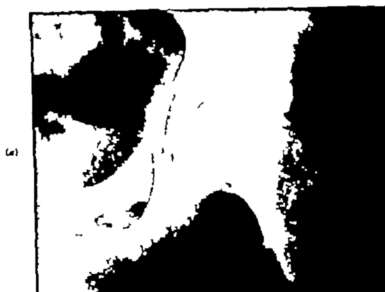


FIG. 175. Active disease in lower thoracic spine with density due to relative avascularity.
(From "Modern Trends in Orthopaedics" (Second Series). Edited by Sir Harry Platt. Butterworth & Co. (Publishers), Ltd.)

This is of inflammatory nature and precedes the erosive influence of granulation tissue. There are, on the other hand, evidences of necrosis due to avascularity. The extent to which arterial occlusion and thrombosis develop is not in tuberculosis so rapid, or so extensive in the earlier stages, as is found in pyogenic infections of bone. Consequently massive sequestration is rarely encountered. On the other hand, necrotic areas of bone generally having indistinct outlines and occasionally lying within bony cavities are evidence of such necrosis. It is often difficult in radiographs to interpret exactly the nature of the changes in bone density and to determine when apparent increase in density

is due to avascularity or to the healing process of deposition of bone and so-called *sclerosis*. Generally the matter can only be determined by serial radiographic studies. The distinction is of importance and is well illustrated by the evidences of density seen early in affected vertebral bodies. The contiguous bodies may show up clearly as of



(a)



(b)

FIG. 176. Two types of radiographic bone density (a) active tuberculosis of hip with avascular bone (acetabular) and sequestrum, (b) the same hip after operative treatment showing dense bone of repair and function.

(From "Modern Trends in Orthopaedics" (Second Series). Edited by Sir Harry Platt. Butterworth & Co (Publishers), Ltd.)

greater density than the vertebræ above or below. The exact interpretation of this change is not easy but it does suggest a relative diminution of blood flow in the area as compared with the hyperæmic osteoporosis of the unaffected vertebræ. In certain cases, however appearances of density which may also be seen in other regions in tuberculosis are so marked as to suggest definite avascularity. The virulence of tuberculosis in its destructive

reached the stage of spasm. The pre-requisite of the examination for muscle spasm is to achieve relaxation so far as it is possible, and to measure the extent to which this relaxation is achieved and the degree of the return of spasm. For example, in the erect spine it may be difficult to estimate the extent of muscle spasm because the muscles are called upon for the maintenance of general bodily balance and so the element of rigidity may be disguised.

When the patient is recumbent in the prone position after maximal relaxation has occurred, the examiner can demonstrate the rigidity by lifting him into hyperextension from the thighs. Normally a clear concavity of the dorsal surface of the spine from the mid-thoracic to the sacral region can be achieved, with the upper part of the abdominal wall still in contact with the couch. At an early stage in spinal tuberculosis this concavity is lost and the trunk rises from the examining couch in a straight line with the thighs, the patient merely resting on his upper sternum.

Deformity may be due to the contracture of spasmodically contracted muscles or due to destruction of articular tissues by the disease. While the latter shows that the disease is well advanced, the deformity due to muscle spasm may be seen early. In the spine undue flattening of the lumbar area may appear before destruction has caused a kyphus. A kyphus may start as a local slightly raised prominence of one vertebra. This suggests that the disease has already advanced to destruction. In the hip and knee, deformity is more frequently "apparent" purely as the result of muscle spasm.

In those joints which are near the surface of the body, for example the knee, elbow, wrist and ankle, deformity may be seen as swelling. Swelling of the synovial tissues is only partly due to the increased secretion of synovial fluid and exudate. The synovial membrane as it becomes invaded by the tuberculous process becomes velvety in thickness and appearance. The swelling tends to involve the extensions of joint cavities, such as those bursae which commonly communicate with joints, for example, the subpsoas bursa at the hip joint and the semimembranosus bursa at the knee. Tendon sheaths in the neighbourhood of joints may be affected secondarily; this is particularly seen at the wrist joint.

Abscesses which may appear as swellings on the surface of the body can travel far from the primary focus. Extraordinary examples have been quoted in the literature. In cervical disease the abscess usually is in the retropharyngeal area or posterior triangle of the neck. In dorsal disease abscesses may enter the intercostal spaces and travel forwards into the breast, here causing difficulty in diagnosis from tuberculous mastitis. Abscesses in the intercostal region, however, may also be due to disease of the costal joints or come to the surface from mediastinal infections. In the lumbar region the abscesses appear in two common positions, one in the loin through the lumbodorsal fascia, either in the renal angle or in the area of Petit's triangle. More commonly lumbar abscesses appear in the inguinal region and they, with psoas abscesses, generally spread deep to the iliac fascia and form a large swelling palpable on the inner aspect of the iliac crest, or may extend below the inguinal ligament in front of the hip joint. If abscesses are allowed to open on to the surface of the body they lead to sinus formation, a serious complication.

The General Principles of Treatment

The most important principle of treatment in tuberculous disease has long been, and still is, the raising of the natural resistance of the body to the invading organisms.

rmerly almost the only means of doing this was by the segregation of patients in ititutions where the most perfect hygienic facilities were available and every known ans could be employed for the improvement of the individual's constitution while at same time putting the affected parts at relative rest. The use of open air the graduated plication of sunlight, good food, and an ordered routine of life were combined with intage of diseased joints in the position that was considered optimal for function if

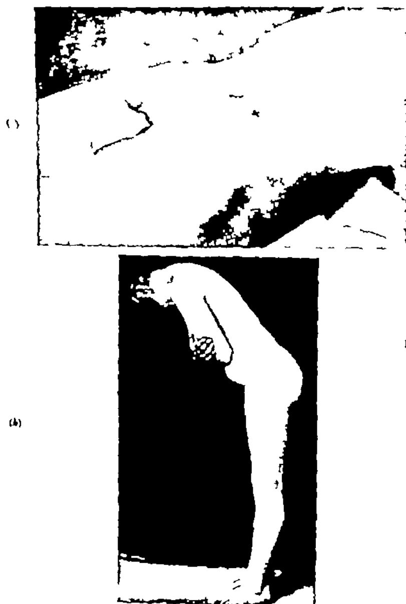


FIG. 178 Active spinal tuberculosis with iliac abscess, (a) in recumbency (b) standing and showing rigidity on attempted flexion.

as was generally expected, ankylosis occurred. Treatment along these lines often involved one or two years away from home, and the inevitable development of a mentality highly coloured by the absence of the normal activities of life For children in the formative years this was particularly harmful. Although these circumstances were mitigated between the two World Wars by the development of special hospital schools in which treatment and education could go hand in hand, it was only a mitigation and could never be accepted as ideal With the advent of antibiotic drugs there has been a tendency to apply to tuberculosis with more assurance of success, the principles which are applicable to the more acute forms of infection, namely the surgical evacuation of abscesses and necrotic material the excision of foci and the earlier use of surgical procedures which formerly were only carried out when the disease had become quiescent.

The disease, however still calls for a long programme of treatment. It is still necessary to combine the use of antibiotic drugs with the care of general hygiene and to maintain the psychological welfare of the individual Nevertheless, the principles of treatment remain the same although the period of time may be shorter

Continuity of Supervision and Treatment

In all tuberculous patients an essential of treatment is the close observation of progress both clinically and by regular laboratory studies not only in so far as relates to the major focal lesions but also of the patients general state. The frequency of such tests as the erythrocyte sedimentation rate or the examination of the urine should not be less than six weekly and the radiographic progress should be studied at least two monthly so that a trend may be observed, which will be a guide to the time and method of treatment. Decubitus brings its own risks and disorders due to it must be anticipated and prevented notably urinary stagnation, infection and calculus formation. Furthermore the possibility of other foci of tuberculous infection must be kept in mind Occasions infrequently arise where interruptions of strict bed immobilization may be desirable so that while the disease is quiescent controlled activity may be given. In this way mechanical stability of a focal lesion may be improved and the general well-being improved. For example in tuberculous disease of the spine it may be a good plan in the later stages to allow a patient to get up and about in a plaster jacket for a period. In this way mutual contact of affected vertebral bodies may lead to greater stability of the posterior fusion obtained later by surgical means. Within the section dealing with spinal tuberculosis will be set out the major details of the treatment of arthrosteal tuberculosis such as will also be applicable to other sites of the disease together with a discussion of the special features of the local treatment of the spine itself

TUBERCULOSIS OF THE SPINE

This, the commonest site of bone and joint infection is, as already stated, most frequently of the human type even in children It appears to arise by hæmatogenous spread from lymph gland infection generally mediastinal or mesenteric. The characters of spinal disease are different in each of the four anatomical regions. There is a natural history in the evolution and response to treatment which is typical of each, particularly in childhood, and the one feature which differentiates the thoracic from the other regions is the obvious one of its relationship to respiratory function.

Diagnosis. The patient who has for long been ill complaining of spinal pain, worse at night with muscular spasms, increasing spinal deformity and perhaps an abscess, presents little problem in diagnosis having come to this point he becomes a social problem of possible tragic consequence. It must be recognized that the development of arthrosteal lesions in tuberculosis is an insidious process and the early symptoms are often vague. Continued malaise of uncertain origin with fatigue and unexplained persistent discomfort may be the earliest symptoms.

Pain. The vagueness of pain reference in the earliest stages of spinal disease may for long be regarded as of rheumatic origin and be treated as such Backache is common enough in many diseases. In tuberculosis it may not be felt at the site of involvement but may be referred to points some distance away by evoking spasm in different portions of the sacrospinalis musculature and by segmental reference through the spinal nerve roots. Thus intercostal neuralgia, epigastric or lumbar pain may be found in disease of the thoracic spine. In the lumbar region pain may be referred to the abdomen, pubic area, the hip, sacrum and even give rise to sciatica. The pain is often worse at night and may wake the patient from sound sleep in young children it may cause much so-called "irritability" (night cries).



FIG 179 Severe kyphus due to advanced destructive disease of the dorsal spine (associated with herpes zoster) and with multiple draining sinuses in both loins and below right great trochanter

Rigidity and Muscle Spasm. In the more mobile cervical and lumbar segments muscle spasm leads to early rigidity that is easily detectable. In the dorsal region it may be less obvious but a useful test is to carry out gentle hyperextension of the spine in the prone position lifting the patient carefully from his thighs. Normally it should be possible to lift the pelvis well clear of the examining couch with the patient's chest wall still in contact with it but in the presence of spinal muscle spasm the whole trunk will tend to rise from the couch in one rigid unit when the pelvis is elevated.

Other Symptoms and Signs. Pain and rigidity are common in other spinal diseases and by themselves are not diagnostic. The clinical signs which are clearly so are the presence of the characteristic deformity—a *kyphus*—and a cold abscess both of which are late signs. The diagnosis should be made before these appear Although with pain

and rigidity the constitutional condition of the patient may suggest tuberculous disease, early diagnosis can only be confirmed radiologically

Deformity Characteristically this is seen in the dorsal region as an angular kyphus or gibbus In its earliest form it may merely be a prominence of one or two spinous processes with perhaps a widening of the normal interval between two of them. To this point is often localized tenderness on percussion and this may be the site of pain on jarring the spine, either by percussion elsewhere or in the course of the normal incidents of life. Later in the disease kyphosis becomes a much more obvious sign when many vertebræ are affected In the cervical and lumbar areas the destructive process in the vertebral bodies may advance considerably before the kyphosis becomes apparent as more than a flattening of the normal posterior concavity

Cold Abscess. These may travel considerable distances before appearing on the surface of the body Treves reported a case in which a cold abscess pointing on the medial side of the ankle arose from tuberculous caries of the cervical spine. Usually tuberculous abscesses take a rather shorter even though devious course. In the cervical region abscesses commence as retropharyngeal collections and spread into the posterior triangle they are to be distinguished from abscesses arising in the cervical lymph glands. In the dorsal region pus tends to be confined within the thoracic cage as paravertebral fusiform abscesses but not infrequently an abscess may appear on the surface having passed through the intercostal spaces sometimes following the posterior branches of the spinal nerves to a point just lateral to the spine or it may pass forwards coming out in the anterior intercostal or mammary areas Such an abscess must be distinguished from one arising from the mediastinal lymph glands, the lungs, the mammary glands or the costal skeleton. In the lower dorsal and in the lumbar areas abscesses tend most commonly to descend by gravity in the retroperitoneal fascial planes more particularly into the fascial sheath of the psoas muscle. Nevertheless they may pass directly through the intermuscular planes of the sub-costal renal angle and appear on the surface of the back and must here be distinguished from perinephric abscesses. Although characteristically a psoas abscess may come to the surface in the groin in front of the hip joint, more usually it first spreads into the iliac fossa upon the surface of the iliacus muscle and bulges forwards under the lateral abdominal muscles above the inguinal ligament and medial to the iliac crest. Occasionally lumbar abscesses, and particularly those from the lowest area and from the sacro-iliac joint, may pass out of the pelvis through the sciatic notch to appear on the lateral side of the thigh. Any abscess if left untreated may rupture through the skin and lead to the formation of sinuses. They may ulcerate into the viscera and form fistulæ or into serous cavities, e g. pleura.

Radiological Diagnosis. The earliest radiographic signs in the spine are areas of lessened density suggesting an invasive lesion with removal of bony substance affecting the cortical margins of the vertebral bodies generally on both sides of the intervertebral disc. Commonly this affects the anterior areas, but occasionally th[illegible] process affects the whole substance of the vertebra or the posterior part alone or th[illegible] y appear as a single cystic area within the vertebr[illegible] centrum. Narrowing o[illegible] graphic clear area of the intervertebral disc wh[illegible] s its destruction, ad[illegible] two vertebral bodies appear to collapse int[illegible] This collapse [illegible] ops more markedly in front and so initiates [illegible] which leads to t[illegible] r kyphus. At an early stage the [illegible] shadow of the [illegible] granul[illegible]

or abscess will be found. It is best seen in the mid-thoracic zone against the contrast of the radio-translucent pulmonary areas, but the observer must differentiate between such an appearance and the shadows of normal mediastinal structures. In the lumbar region there may be *loss of outline or bulging laterally of the* lateral margin of the psoas muscle shadow

In advanced cases of spinal tuberculous disease the destructive process involves more than two vertebræ in some cases multiple separate lesions may be found. The tendency



(*a*) (*b*)

FIG. 100. Tuberculosis lower dorsal spine, showing in (*a*) paravertebral abscess, and in (*b*) early destruction of contiguous vertebral bodies.

(From Modern Trends in Orthopaedics (Second Series) Edited by Sir Harry Platt, Butterworth & Co. (Publishers), Ltd.)

for the tuberculous process to spread insidiously from the focal site is shown by the way in which apparent erosive destruction may be found in the anterior or lateral surfaces of the vertebral bodies extending a considerable way upwards and downwards from the primary site of disease.

While it will be noted that radiographically the early characteristics of tuberculous disease is focal bony destruction with surrounding osteoporosis (i.e. the general thinning of bone texture by vascular absorption) partly due to hyperæmia and possibly contributed to by disuse atrophy nevertheless there are not infrequently signs of avascularity and necrosis (even sequestration) It will be remembered that pathologically a feature of the tuberculous process is endarteritis. This appears *radiologically in the local areas of* relative density which leads to fragmentary sequestration in the bony lesions A more massive appearance of avascularity may be found in some spinal radiographs where the two vertebræ predominantly involved may throughout their structure present a striking relative increase of density compared with those vertebral bodies above or below which

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show the osteoporosis of hyperæmia or disuse. This type of denseness tends to diminish as treatment proceeds.

In the course of the disease particularly during treatment, serial radiography at regular intervals is of importance in guiding the clinician upon its progress. One radiographic examination cannot determine whether the disease is active or quiescent More valuable are the comparative signs of the destructive process and its natural healing the cessation of erosion the reduction of paravertebral abscess shadows improved density of bone structure and the presence or absence of attempts at local intervertebral fusion either across the site of the central lesion or by periosteal new bone formation generally seen in front of the lesion. The improved density of bone and the marginal sclerosis of healing must be distinguished from the evidence of avascularity and necrosis above mentioned

Differential Diagnosis. *Spinal Tuberculosis must be in mind when considering any* of the causes of chronic backache even in the absence of the characteristic clinical appearances. It is not necessary to outline here every possible disease—they are legion. What is loosely called Rheumatic Disease must come first because it is the commonest if under this title is also included the chronic pain of fatigue and occupational stress. Other structural lesions of the spine associated with trauma ranging from fractures to protrusions of intervertebral discs, diseases of the skeleton such as osteoarthritis, ankylosing spondylitis (particularly in low lumbar and sacro-iliac disease) osteomyelitis (including actinomycosis), septic arthritis (e g. typhoid), neoplasms (both primary and secondary) including such bone marrow diseases as myeloma, leukæmia and lymphadenoma.

Secondly there are the large group of visceral diseases which may have a spinal reference of pain and conversely there are many occasions when spinal disease may have a visceral or thoracic and abdominal reference In the differentiation of thoracic disease or alimentary or renal tract lesions from spinal tuberculosis mistakes have often been made

There is a third important group which comprises the intra-thecal lesions including spinal cord tumours.

Lastly in all cases of chronic backache, for which no cause can be found, where the clinician may feel that psychosomatic or functional factors are responsible, particular care should be taken to consider tuberculosis in the context of the other three groups of conditions mentioned above.

Peculiarities of Tuberculosis of the Thoracic Spine

As stated above in the thoracic spine tuberculous disease behaves differently from that in the cervical and lumbar areas. It is a more serious disease and its evolution and progress are affected by the physiological conditions within the thoracic cage. The vertebral bodies move with every respiratory action and they may be affected by the rhythmic pulsatory pressure of the aorta These circumstances, however are common to the lumbar region. What is different is that within the more rigid thoracic cage pneumodynamics play a greater part. In other words, with every respiratory cycle there is a variation from inspiratory suction to expiratory pressure. These alternations from negative to positive pressure influence all soft tissues within the rigid thorax. The softer walled structures are more affected and, as with the larger veins, so with an abscess.

This influence is probably more important than any aneurysmal effect produced by pressure on the abscess from the aorta. Certainly in the thoracic region of the spine the spread of abscesses upwards and downwards far from the seat of the major lesion, their tendency to burrow beneath the anterior common ligament with the consequent tendency for tuberculous granulation tissue to erode distant vertebræ, is characteristic. In children tuberculous disease of the thoracic spine is particularly malignant compared with that in the lumbar region. In the latter the prognosis is relatively good; bony destruction is not so extensive and the resultant deformity is relatively slight. The lesions higher up, particularly those from the level of the seventh to the eleventh dorsal vertebræ, have an extremely bad reputation for extensive and uncontrollable destruction with very severe deformity.

Respiratory function obviously also plays a part in the greater frequency with which the pleural cavity is involved by rupture of a paravertebral abscess than is the peritoneum. It is true that the pleura may be affected directly by extension of granulation tissue from the tuberculous focus without actual rupture of a paravertebral abscess. The latter circumstance, however, is a serious and alarming complication, which, nevertheless, may respond well to early and, if necessary, repeated removal of the pleural contents by aspiration.

Paraplegia is a further complication which occurs most commonly in the thoracic segment.

Tuberculosis of the Sacroiliac Joint. This is the fourth area of the spine to be considered. Although not unknown in children the disease of this joint is commoner in adults, and in men is particularly associated with genito-urinary tuberculosis. In the past it has had a bad reputation for chronicity. It may start in the articulation itself and cause a more or less general destruction of its surfaces or it may arise in the neighbouring bone, commonly the ilium, and spread into the joint secondarily.

Clinically pain is commonly gluteal and sciatic in distribution and because of its insidious origin is prone to be regarded as rheumatism or sciatica. Stiffness in the lower spine does not distinguish it from other causes of low back or gluteal pain; furthermore symptoms may all be referred to the front of the hip. Abscesses either in the buttock or in the iliac fossa may proclaim that the disorder is tuberculous and will clarify the diagnosis in many cases. Pain in the joint on compression of the pelvis from side to side though often present is not diagnostic of tuberculosis. Difficulty radiologically is aroused particularly by ankylosing spondylitis which, occurring in the same age group of young adults, produces loss of clarity in the picture of the articular margins, with areas of apparent erosion and patchy osteoporosis and sclerosis in the neighbouring bone. Sometimes in tuberculosis a tell-tale area of periostitis may appear in the under surface of the ilium close to the joint, and there may be a clear abscess cavity communicating with the joint and possibly containing an obvious but ill-defined sequestrum.

In treatment it is obvious that associated visceral lesions will be looked for but the general and local care is similar to that for low lumbar tuberculosis—open air hospital care, rest in a plaster shell, antibiotics, and attention to the patient's social needs. Access to the sacroiliac joint is easy and consequently surgical treatment more readily performed. Abscesses must always be evacuated by aspiration but large abscesses in the iliac fossa if recurrent may be best dealt with by incision through the retro-peritoneal plane followed by careful primary closure of the incision through the abdominal muscles. Curettage

of the bony lesion is effected through a window cut in the posterior part of the ilium, an approach being used similar to that devised by Smith Petersen for sacroiliac arthrodesis the latter operation being desirable in some cases in order to achieve stability of or to eliminate any remaining movement in the affected joint. The duration of treatment, as in the lumbar region, depends on whether or not there is any associated visceral disease. If uncomplicated then one should expect the patient to be up and about in some form of low spinal support in six months.

Treatment of Spinal Tuberculosis

The patient is best dealt with in an orthopædic unit for long stay cases in which, apart from the special and general medical and nursing care, he can at the same time have the benefit of the auxiliary services of education and occupation. On admission a complete medical overhaul must be carried out so that any other foci of tuberculous disease may be looked for and if present, treatment for them planned. This must, in any case include complete radiological studies of the lungs and bacteriological examination of the urine. The erythrocyte sediment rate and a complete blood count will be checked and in children the Mantoux reaction will be tested. Unless previous radiographic studies of the spine have been performed in the unit in which the patient is being treated it is advisable to have fresh radiographs taken to conform with the technique which will be followed in the course of treatment. Bed rest for a few days to familiarize the patient with the hospital routine should be followed by preparation for the application of physiological control which generally is provided by a posterior plaster of Paris shell or "plaster bed."

At the same time the administration of antibiotic drugs will be commenced. This is the same as for tuberculosis elsewhere and the dose of each drug is usually based upon the weight of the patient. In an adult this amounts to approximately 1 gramme of streptomycin daily for 90 days together with para-amino salicylic acid (P.A.S.) 8–10 grammes for the same period. The P.A.S. is continued for as long as the patient can tolerate it and after the 90 days it is given with Isoniazid 4–500 mgm. daily which is continued indefinitely.

Preparation of the Plaster Shell

The patient is gently rolled on to his face and lying upon waterproof covered pads or cushions under the pelvis, lower abdomen and thorax—a small gap should be left free under the upper abdomen for respirat[illegible] ents. The head is su[illegible] in the neutral position with a pad under the for[illegible] similar pad will be pla[illegible] th the front of the ankles. All of these pads [illegible] ut six inches in hei[illegible] with the knees resting upon the plaster table it [illegible] nd knee joints will [illegible] exion. Furthermore the limbs should be so a[illegible] there is an angl[illegible] tion of approximately 30° between the two thi[illegible] n of the patient [illegible] hs and lower [illegible] ll greased with petroleu[illegible] e) and if the [illegible] le spine is inv[illegible] d is covered with close [illegible] gette. The a[illegible] bducted to a n[illegible]

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The finished product should in an adult be of an even thickness amounting to about ⅜ in When the plaster mould has set it is carefully raised from the patient and placed in a dry warm, airy place so that it may harden with the evaporation of excess moisture After two days it will then be possible to cut off rough edges to shape it around the shoulder an opening is made at the site of the natal cleft and between the thighs for nursing purposes and a bridge is left between the knees. The lower end is trimmed just above the ankles. The whole shell may be lined with a thin, even layer of felt and covered with stockinette This shell is then supported and elevated from the bed mattress upon either a specially made wooden frame or preferably upon a Bradford frame as has already been described (p 248). When the latter is used it is easy to fix to its upper end, laterally extending tubes or arms through which block and tackle suspension may be applied with counterbalancing weights as described by Nangle and Dommisse By this means the patient is encouraged to vary his position by inclination from side to side and with his head raised or lowered in so doing one step is taken in preventing one of the undesirable effects of prolonged decubitus, i.e. renal stagnation and calculus formation. When the patient is first placed in the shell it is advisable during the first week to turn him on to his face two or three times so that the back may be inspected to make sure that there are no irregularities and so that the skin may be cleaned and treated with spirit and powder Thereafter he should be turned once a week. Turning is peformed by strapping on to the front of the patient and his shell, another Bradford frame so as to retain his position undisturbed during the movement.

Open Air and Sunlight

The stimulus to metabolic processes by open air is of greater importance than exposure to sunlight. Indeed for patients who have not been much exposed previously actinic irradiation may be quite harmful. The sudden steady release of the breakdown products produced within the skin has been known to reactivate or aggravate tuberculosis. The graduated exposure of areas of the body to air and sky-shine should avoid any risk of erythema and will allow an extremely slow pigmentation to occur Special care is also required to protect the eyes of patients, even from sky-shine, where they are lying for long periods in dorsal decubitus

Diet

This should be ample and well balanced with adequate vitamin content. While the diet should meet the increased demands of metabolism it must be controlled sufficiently to avoid excessive weight increase Of special importance is fluid intake in order that renal output should be maintained at a time when calcium excretion may be increased through the relative atrophy of skeletal structure during immobilization

Education and Occupation

Quite apart from the social upheaval that may be caused by such a major illness as tuberculosis, social factors not infrequently provide one of the factors that have precipitated the disease. Education and occupation are therefore psychologically important and can provide, through the creative effort which is inculcated, a valuable influence in raising morale and in improving the mental outlook.

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The plaster shell may then be prepared in two ways. Either specially wide plaster bandage rolls or strips may be soaked and unrolled on to the back and legs, or sheets of several thicknesses of plaster muslin may be soaked in a plaster cream and similarly applied to the whole posterior aspect of the patient.

The finished product should in an adult be of an even thickness amounting to about ¾ in. When the plaster mould has set it is carefully raised from the patient and placed in a dry warm, airy place so that it may harden with the evaporation of excess moisture. After two days it will then be possible to cut off rough edges to shape it around the shoulder an opening is made at the site of the natal cleft and between the thighs for nursing purposes and a bridge is left between the knees. The lower end is trimmed just above the ankles. The whole shell may be lined with a thin, even layer of felt and covered with stockinette. This shell is then supported and elevated from the bed mattress upon either a specially made wooden frame or preferably upon a Bradford frame as has already been described (p 248). When the latter is used it is easy to fix to its upper end, laterally extending tubes or arms through which block and tackle suspension may be applied with counterbalancing weights as described by Nangle and Dommisse By this means the patient is encouraged to vary his position by inclination from side to side and with his head raised or lowered in so doing one step is taken in preventing one of the undesirable effects of prolonged decubitus, i e. renal stagnation and calculus formation. When the patient is first placed in the shell it is advisable during the first week to turn him on to his face two or three times so that the back may be inspected to make sure that there are no irregularities and so that the skin may be cleaned and treated with spirit and powder Thereafter he should be turned once a week. Turning is peformed by strapping on to the front of the patient and his shell, another Bradford frame so as to retain his position undisturbed during the movement.

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Physical Therapy

The one aspect of physical therapy which is of importance is remedial exercise to *maintain activity in parts not affected by the disease*. Exercise for the limbs should not be violent and at first should simply be of supported type the joints should be put through their full range of movement at least twice a day and as the disease comes under control the movements can become more active. At least once a day for a period special attention should be given to respiratory exercises to improve vital capacity Even in thoracic spinal disease the benefits outweigh any theoretic disadvantage.

Operative Surgery

Operative surgery in assisting the natural processes of healing, has three aims first the radical treatment of necrotic zones secondly the treatment of local complications thirdly the achievement of consolidation when the disease is quiescent.

The first aim of dealing with necrotic tissue is an ancient principle of surgery which fell into disfavour in tuberculosis until recent improvements in antibiotic treatment did so much to strengthen constitutional therapeutics. Tuberculous abscesses are reservoirs of tubercle bacilli and of the toxic products of necrosis. They should be eradicated. The simplest way is by aspiration nevertheless open operation and evacuation with the excision of necrotic material has become an appropriate method which is now more frequently applied.

Aspiration Techniques. An abscess should, as far as possible, be dealt with while it is still beneath the deep fascial plane. If it becomes subcutaneous the risks are much greater of rupture spontaneously through the skin or through the track of an aspiration needle. For the aspiration the materials for a local anæsthetic will be needed and the actual aspiration is done through a large bore needle or trocar and cannula which may be attached to a syringe such as Gauvain s having a wide bored nozzle. In large abscesses it is convenient to have a two way nozzle so as to facilitate both aspiration and disposal. In every case the aspiration cannula should pass *obliquely* through skin and soft tissues at a point several inches from the summit of the abscess swelling. At the completion of aspiration *1 gramme of streptomycin should be injected into the cavity*

Open Evacuation of a Lumbar Abscess. This is indicated particularly when, because of the caseous nature of the material within the abscess, it is not possible to carry out efficient evacuation. Sometimes also the patient's clinical condition and a persistently raised erythrocyte sedimentation rate may indicate that the abscess should be dealt with more radically

An incision similar to that used for exposure of the kidney is made in the loin and extending forwards to a point an inch or so above and in front of the anterior superior iliac spine. The external oblique is split in the line of its fibres and the internal oblique and transversalis in the line of the skin incision except at the lower end of the wound where they may be separated in the line of their fibres. The extra-peritoneal fat and peritoneum are stripped inwards off the iliacus to expose the wall of the abscess through which an opening is made that can admit two rubber tubes one for suction and the other for irrigation. The latter can be passed high up in the abscess and so facilitate its clearance *If possible the abscess wall should be sutured after inserting* the streptomycin.

For an abscess in the upper lumbar region the exposure closely resembles that used for lumbar sympathetic ganglionectomy

Costotransversectomy This operation was introduced by Ménard in 1894 as a means of relieving tension in thoracic paravertebral abscesses in the treatment of paraplegia. Lately it has assumed a greater importance as a means of evacuating these abscesses and for the removal of necrotic tissue from vertebral lesions in otherwise uncomplicated cases of spinal disease. In Britain a particular enthusiast in the use of the method has been M. Wilkinson. Griffiths, Seddon and Roaf in their recent work to which reference will be made later have gone so far as to state that it "should be performed in all cases of thoracic tuberculous caries with or without paralysis if the radiographs show the shadow of an abscess and if the disease is recent."

The steps of the operation have already been described (*see* p 255). It remains only to add that if a wider exposure is needed to deal with a large vertebral lesion two ribs and transverse processes can be excised and after separating the intercostal nerves from the vessels the latter with the intercostal muscles and pleura can be depressed in order to obtain a better view of the lateral aspect of the lesion in the vertebral bodies

Spinal Fusion. This is not a curative procedure but is important as a stabilizing influence by giving bony fixation of the affected area of the spine. If carried out when the disease is quiescent it thus consolidates cure and lessens the risks of later recurrences of activity This operation also has been described in the general section of this volume. One should add that in the thoracic region iliac grafts have a particular usefulness because they can be well shaped to the kyphotic deformity if this is severe ribs are also useful for the same reason. In the lumbar region if only two vertebræ are to be arthrodesed (and there are a few occasions in which this is justified) then a thick piece of the posterior portion of the ilium shaped in the form of a letter H can be driven between the two spinous processes into contact with the laminæ Where however three or four should be fused (which is more usually advisable) then a denser and stronger material is necessary to withstand flexion and torsional stress. For this reason grafts taken from the patient's tibia are most suitable. Though there is a vogue for the use of homogenous bone from frozen stock the author of this article is not greatly in favour of them, for reasons that have already been given (*see* p. 255).

Curettage and Fusion of the Sacro-iliac joint has already been described (p. 256)

The treatment of sinuses is discussed on p 317

POTT'S PARAPLEGIA

This complication of spinal tuberculosis has been known eponymously since the appearance of the classic paper by Percivall Pott in 1779 It had also been clearly described in the same year by David of Rouen and had been well known to the ancients. Modern French workers have given it particular attention. In Britain important papers were published by Seddon and Butler in 1935 The most recent work is an exhaustive study by Griffiths, Seddon and Roaf whose conclusions are here quoted. In spite of the advent of effective antibiotics which have done so much to control tuberculous disease and its complications, tuberculosis in some countries is still a very serious problem. Even in Great Britain it is still an important disease and Pott's Paraplegia is not uncommon

Clinical Features. Where the incidence of spinal disease is particularly great in young children, paraplegia may appear at an equally early age but usually some years after the onset of the disease, being most frequent in adolescence. Nevertheless 23 per cent of cases of paraplegia came with this as the presenting symptom of spinal disease. Furthermore in the great majority paraplegia occurs within a year of onset of the disease and may recur more than once. It has been found with no demonstrable radiological evidence of spinal disease, due to an intra-spinal tuberculoma (spinal tumour syndrome). While usually due to destruction of the vertebral bodies paraplegia can also be caused by disease arising in the posterior neural arches. The French writers, and later Seddon, differentiated for prognostic reasons between paraplegia of early and late onset, but Griffiths, Seddon and Roaf are now doubtful of this distinction.

Paraplegia may develop insidiously or quite rapidly with either weakness or spasticity in the legs but without pain Sensory loss is a less prominent feature. Hyperexcitability of the lower motor neurone reflexes, clonicity and an extensor plantar response may lead to severe flexor spasms or to a complete flaccid paralysis. The type of neurological change is dependent upon the site of the lesion in the cervical area it may cause a tetraplegia. In rare cases where pressure occurs more laterally in the spinal canal the paresis may resemble that of the Brown-Séquard syndrome. All paralysis in tuberculous patients should not be regarded as necessarily due to spinal disease as was demonstrated in one patient, operated upon by the author in whom miliary tuberculosis was associated with paraplegia but which was found to be due to a large neurofibroma (dumb-bell tumour) extending from inside the spinal canal through an intervertebral foramen into the mediastinum.

Paraplegia may occur so rapidly as to suggest a major disaster under these conditions surgery may become a matter of emergency Further understanding is dependant upon knowledge of the pathological conditions.

Pathology The lesion which causes paraplegia is not primarily one of the spinal cord and meninges but is an extension of the tuberculous process and its products from the vertebral bodies into the spinal canal. The cord and meninges are not compressed between abnormal tissues in front and the laminae behind, but are stretched across whatever is impinging upon the anterior wall of the theca. This may be abscess arising directly from the vertebral lesion or secondarily invading the spinal canal as an extension from a paravertebral abscess. Caseous granulation tissue, sequestrated bone or intervertebral disc substance all may take part in the impingement upon the front of the theca. In late cases a slow crumbling lesion may slowly extrude material into the spinal canal or the theca may be indented over a bony edge caused by pathological dislocation. Even in completely healed lesions with no sign of pathological activity a sharp angular spur at the apex of an "internal kyphus" may cause paraplegia. Why this should occur is difficult to account for and longitudinal as well as circular shrinkage of the cord has been given as a possible answer In addition it would seem possible that the bowstring effect of tension against the anterior protruberance is accentuated by the severe lordosis which occurs above and below the kyphus, particularly is this so in the upper dorsal region. Such a possibility would be contributed to by peridural fibrosis and consequent fixation of the theca.

A rare cause of paraplegia in tuberculosis (recorded by Seddon) is thrombosis of the spinal vessels with impairment of the blood supply to the cord.

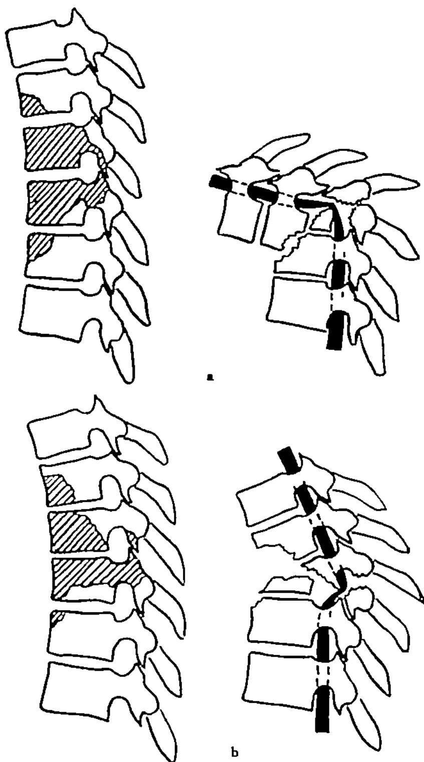


Fig. 181 Diagrams illustrating the production of pathological dislocation in tuberculosis of the spine. In high thoracic disease, anterior luxation (*a*) is more likely to occur whereas in lower disease there is more likelihood of the upper spine moving backwards *en masse*

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There are thus inflammatory causes of paraplegia in (1) Abscess, (2) Granuloma, (3) Caseous material, and (4) Infective thrombosis. Purely mechanical causes are (a) Sequestration of bone and disc, (b) Pathological dislocation, (c) Inflexion of the spine, (d) Bony ridge in the floor of the spinal canal.

Prognosis. In the work of Griffiths, Seddon and Roaf 66·5 per cent of patients recovered from paraplegia. The percentage of recovery was slightly better in children and a little worse in adults. There appeared to be no significant difference between those cases of early onset and those in which paraplegia came on later. As in other neurological lesions the prognosis was worse where paraplegia of severe degree came on rapidly within a week or less. The seriousness of the prognosis under purely conservative measures is also shown by a large series described by Dobson (1951). In 394 cases of dorsal spinal tuberculosis, 31 per cent developed paraplegia and of these one in every four patients died and less than a half made a worthwhile recovery.

Treatment. The purely conservative treatment is as already described for uncomplicated spinal tuberculosis. Some writers have emphasized the importance of hyper-extension so as to reduce the amount of internal kyphus, i.e. of the backward projecting vertebral bodies. With better understanding of the pathology this clearly could not have had much beneficial effect. Conservative measures undoubtedly are important accompaniments of other forms of treatment for the tuberculous disease itself. Paraplegia however requires careful assessment at an early stage and operative intervention should be undertaken early, in particular when paralysis has been of rapid origin or in which a more slowly developing paresis is not responding to rest.

Operative Treatment. *Laminectomy* has been discarded because of the impossibility of dealing safely with the actual cause of compression. *Costo-transversectomy* was introduced by Ménard (1894) because of the belief that the paraplegia was chiefly due to abscess and that if the paravertebral abscess was drained this would automatically reduce tension in its intraspinal extension. This could not relieve other causes of pressure upon the cord and as the operation was often complicated by later secondary infection it was abandoned. Recently it has been used more often in non-paraplegic cases of spinal tuberculosis as advocated by Wilkinson and has been discussed in a previous section of this article. The essential need is to remove the cause of pressure upon the cord actually at the site in the anterior wall of the spinal canal. This seems to have been first performed in 1933 as a planned operation by Capener whose description of this first operation was recorded by Seddon (1935). Further operations led to the development of a technique which the author called *Lateral Rhachotomy* (Capener 1954). In the meantime Dott and Alexander (Alexander 1945) had independently developed a similar procedure which they described as *Antero-lateral Decompression*.

Lateral Rhachotomy. This operation of opening into the vertebral column from a lateral approach was designed for anterior decompression of the spinal cord in cases of Pott's paraplegia. It has a wider use, notably for the biopsy of vertebral neoplasms. For the latter purpose it is little more than a costo-transversectomy but for the former the operative field is wider.

An incision encompassing at least six vertebræ is required and it extends convexly from and to spinous processes and laterally to the level of the rib angles. The trapezius muscle is reflected laterally from the spinous processes and three ribs are stripped subperiosteally from their angles to the transverse processes the central rib being the one

leading to the main focus of disease. The transverse processes of the upper two vertebræ are excised to their bases and the upper two ribs sectioned at their angles and all ligamentous attachments to the costal heads are divided so that the entire central end of each rib may be removed. The upper two intercostal nerves are exposed and followed to the spine the lower of the two being divided about an inch and a half away from the spine and followed inwards to the intervertebral foramen in this its sympathetic communications will later have to be sectioned. The intercostal muscles, the pleural periosteum and the intercostal vessels will now be depressed inwards and gradually stripped by careful blunt dissection from the sides of the vertebral bodies. A paravertebral abscess (in cases of Pott s paraplegia) may now be opened and if so should be evacuated. With the divided intercostal nerve as a guide the pedicle above and below is exposed and the soft tissues still further moved off the side of the vertebral column so that the tuberculous lesion can be clearly identified. Each pedicle is now removed by nibbling with small rongeurs and the lateral side of the theca can be fully exposed. The cause of compression from the front will then be seen and dealt with bony sequestrum and other intervertebral debris, caseous material etc. being removed. Care must be taken not to leave any sharp bony edge which may lead to further trouble later If the compression itself is due to a sharp spur or projecting edge of a subluxated vertebra (as may be the case in late quiescent lesions) then a cavity must be made in the body of the vertebra into which the bony spur may be brought forward so as to avoid the risk of pushing the spur further into the theca and cord.

Spinal Fusion. As in uncomplicated spinal disease this operation has an important place as a means of completing the cure of the lesion and of stabilizing a vulnerable area. As a primary treatment for Pott s paraplegia it has, contrary to earlier views, no place for the reasons already given above. After completion of the treatment *for paraplegia* it does have a special place which should be emphasized. Where the vertebral lesion has been extensively excised a large bony defect may remain which though it should be encouraged to close by postural means will remain an area of instability Posterior spinal fusion with bone grafts thus becomes a necessary consolidating influence and it should be achieved in all cases.

TUBERCULOSIS OF THE HIP

The incidence of this disease is only second in frequency to that of the spine, and it provides special diagnostic interest because of the great vulnerability of the hip joint at all ages and the variety of lesions which it may present.

Sites of Infection. It is accepted that the disease may commence in *the synovial* membrane or may spread to it at an early stage from a neighbouring endosteal lesion. The particularly vulnerable points are the vascular areas of the metaphysis of the *femoral* neck, the capital epiphysis and the Y-shaped synchondrosis of the *innominate bone* The possibility of multiple foci either at the beginning or soon afterwards is likely *in* view of the ramifications of the peri-articular vascular network. It would, at any rate, seem unwise to regard the extra-articular foci (even such as may be found in the great *trochanter*) as isolated lesions, for experience shows that the joint itself sooner or later almost invariably becomes involved.

Symptoms. Pain in *the region of the hip* or thigh, and a limp (which is less marked after rest) may be the first complaints, and the constitutional disturbance may *be slight*

As the lesion evolves, muscle spasm, deformity with pain at night, restlessness and malaise become more obvious, and some degree of swelling may be noticed in front of the joint.

Signs. Muscle spasm is the feature which dominates all the physical signs in the early stages it largely determines the nature of the patient's limp it causes flexion deformity and limitation of movement and is responsible reflexly for the early and marked muscular wasting which develops

The examination of the patient commences where possible with that of his gait. The *flexion spasm of the hip and the pain cause him to remove his weight from the affected* limb as soon as possible at each step, and to walk with the hip and knee flexed. Flexion of the knee is due to the limitation of extension of the hip joint. In recumbency the degree of flexion contracture of the hip may be masked by rotation of the pelvis to produce lumbar lordosis. Thomas's test requires the elimination of this lordosis by flexing the normal hip fully upon the abdomen. The extent to which the thigh of the affected limb rises off the couch is the measurement of flexion deformity Lateral tilting of the pelvis similarly modifies the appearance of fixed abduction or adduction The former is more likely to be seen in the early stages for in this position the capsular tissues are under less tension. Later however when the inflammatory process and distension has caused softening of the capsular tissues and there is commencing destruction of the articular cartilage, the lateral deformity changes to that of adduction and internal rotation and is associated with marked wasting of the gluteal musculature together with contracture of the psoas and adductor muscles.

In the absence of structural or real shortening of the limb through bony destruction, there may be apparent shortening and this is due to upward tilting of the pelvis on the affected side in order to compensate for fixed adduction. Where, in addition, there is structural shortening then a deformity of adduction may for the same reason cause it to appear greater than it actually is. When measuring for true shortening it is necessary to correct the pelvic tilt and to measure the sound limb in the same relative position of deformity as that assumed by the affected limb

The use of Nelaton's line or Bryant's triangle in localizing the position of the greater *trochanter though interesting, is under modern* conditions superseded by the more accurate information which radiographs provide. Similarly the Trendelenburg test, though positive in the presence of adduction deformity is found in many other conditions in which there is inability to abduct the pelvis upon the femur in the standing posture.

Where pain and muscle spasm are severe it is sometimes found that the normal limb is unconsciously used by the patient as a protective device, its foot being pressed downwards against the dorsum of the foot on the affected side thus weakly providing a certain measure of splintage and distraction. The hip itself may be tender to the touch in front and a sense of fullness may be felt with some increased warmth. These signs may become more *apparent as muscular wasting increases*. The movements of the joint are limited in all directions by muscle spasm and produce pain. If such a hip is left for long untreated, the patient's constitutional state will deteriorate not only because of the tuberculous process itself but also on account of pain and the mental distress and the physical reactions which these produce. It must, however be recognized that all the features noted above, merely indicate the presence of an active arthritic process and the proof that it is tuberculous is dependent upon other investigations.

Special Investigations

Radiographic Studies are important. If the examiner stands at a distance from the trans-illuminated film, minor changes of significance may be more readily apparent than if the film is examined at the usual reading distance. Minor degrees of reduced density affecting the whole bony structure of the hip indicate hyperæmia and osteoporosis. There may be an increase of soft tissue density due to a bulging distended joint capsule and a thickened synovial membrane. Closer inspection is necessary for the detection of small osseous foci, or narrowing of the interval between the articular margins of the weight bearing surfaces of the acetabulum and femoral head due to erosion of the intervening articular cartilage. The later evidences of bony destruction are more obvious. It must be recognized that the radiographic appearances may at first be completely normal

Aspiration of the Hip should be performed by passing a long hypodermic needle down to the head of the femur inserting it through the skin at a point immediately below the anterior superior iliac spine on a level with the tip of the great trochanter and directing the needle upwards and inwards. The needle should be withdrawn slightly after striking the femoral head until fluid can be aspirated into the syringe The fluid is sent for bacteriological examination which should include culture upon the Loewenstein-Jensen medium which has largely replaced the use of guinea pig innoculation for diagnostic purposes.

The Mantoux Test is only of value if negative, for it indicates that the condition present is unlikely to be tuberculous. The erythrocyte sedimentation rate is of no value diagnostically but it is helpful in assessing the activity of the disease and as a guide to prognosis when carried out at regular intervals during treatment. A blood count may show some evidence of secondary anæmia and the absence of leucocytosis may help to distinguish the condition from a pyogenic infection.

Biopsy Where the diagnosis is sufficiently in doubt and where it is not wished to wait for the length of time necessary to obtain the results of culture from aspirates (6–8 weeks) then biopsy of the synovial membrane may give an earlier answer to the question. The hip joint is exposed through a small vertical incision below the anterior superior iliac spine and the interval between the sartorius and tensor fascia femoris is penetrated lateral to the tendon of the rectus femoris muscle the reflected portion of which, as it passes across the capsule of the hip joint, acts as a guide. The capsule is incised vertically the synovial membrane inspected and a suitable portion removed for histological study

The Differential Diagnosis in Tuberculosis of the Hip

Other Infective Lesions. In the more active phases of tuberculous disease the particular conditions to be distinguished are acute septic arthritis and osteomyelitis of the femoral neck or innominate bone. In these the physical signs may be identical but the constitutional changes are those of an acute fever with a high temperature and pulse rate, a leucocytosis and turbid synovial fluid from which the causative organisms may be cultured. In osteomyelitis, however there may be a sterile joint fluid before frank involvement of the joint has occurred. Radiographs may also be negative in the early stages. Furthermore, symptoms and signs in the hip may be produced by any lesion of

the lower end of the femur or knee joint. It must also be noted that psoas muscle spasm with flexion and internal rotation of the hip may result from acute appendicitis, and even from acute renal disease.

Dislocation. Congenital dislocation of the hip should not lead to any difficulty in diagnosis. Its presence in early infancy in an otherwise fit child who though it may have a disorder of gait, does not have the limp of pain nor does it suffer at rest. The physical signs are clear enough excepting in the lesser degrees of dislocation or subluxation. Radiography will clarify the diagnosis.

It must be recognized that, in common with acute suppurative arthritis, tuberculosis may result in dislocation if the pathological process is not brought under control and if the position of the hip is not safeguarded during treatment.

Perthes Disease. In tuberculosis of more insidious origin the common lesion with which it may be confused is osteochondritis of the femoral head (Perthes or Legg-Calvé's disease pseudo-coxalgia). This disease which occurs more commonly in boys than in girls between the ages of 5 and 10 has symptoms and signs which are less obvious and there is little, if any deformity and the limitation of movement does not affect the complete range it is generally that of flexion and internal rotation. The radiography may be entirely negative but after the disease has been present for some weeks the first signs are of relative sclerosis of the femoral head and some apparent widening of the gap between the contiguous articular bony margins due to a relative increase in thickness from swelling of the articular cartilage. The later appearances of coxa plana, fragmentation, etc. are readily distinguished.

Epiphyseal Coxa Vara. In a somewhat older age group this condition may lead to confusion. It is usually found in girls from the ages of 11 upwards and in boys a year or two later When the displacement of the upper femoral epiphysis which causes the condition is slow in development, symptoms of discomfort, limitation of movement and deformity may be slight or not obvious. The patients may have the characteristic appearance of rather heavy robust childhood and may even present signs of hypopituitarism (of Fröhlich's type). The hip may be held in slight external rotation and spasm may prevent internal rotation and flexion. The radiographic appearances are usually characteristic but require careful observation.

Hæmophilia. Sudden hæmorrhage may occur into the hip joint of affected subjects following minor trauma, the symptoms resembling those of a somewhat active early tuberculous joint. The radiographs at first will be negative but after repeated episodes may show erosive changes which, however are generally associated with evidence of bone sclerosis by radiographic increased density Aspiration of the hip will produce blood and it has been claimed that after such diagnostic aspiration the introduction of hyalouronidase may facilitate its absorption.

Chronic Deforming Arthritis. In adults the two conditions which particularly are to be distinguished from tuberculosis fall within the general classification of atrophic arthritis

Ankylosing Spondylitis. This disease arises in young adults particularly during the third decade, generally involving the sacro-iliac and lower spinal joints at an early stage. The patient may however first complain of pain and stiffness in the hip, for the spinal condition may have advanced without any noteworthy disability The history however of a rheumatic like disorder of the lower spine and the presence of a rigid lumbar region,

diminished respiratory excursion and the typical radiological appearances in the sacro-iliac and lower spinal joints should make the diagnosis clear

Rheumatoid Arthritis. Involvement of one hip as a first manifestation of the disease is uncommon, yet as with rheumatoid arthritis elsewhere it is often extremely difficult to distinguish the radiological appearances from those of tuberculosis. The presence of other joint involvement makes the diagnosis of rheumatoid arthritis more likely but when in doubt aspiration or synovial biopsy must be performed.

Osteo-arthritis may give rise to symptoms at any time in adult life from the age of 20 onwards, particularly when the disease supervenes upon a pre-existing congenital developmental or traumatic lesion. While pain and muscle spasm with a limp and deformity may on occasion resemble the signs of a tuberculous hip the absence of constitutional disorder and the radiological appearance of the underlying abnormality with the characteristics of osteo-arthritis, should cause no difficulty

The Treatment of Tuberculosis of the Hip

Before the diagnosis is confirmed treatment must be initiated in a unit where accurate observations may be made not only of the investigations above noted but also as time goes on, of the response to graduated function. For children in particular the many minor traumata to which the hip is exposed and the various possibilities which have been mentioned may make accurate diagnosis impossible. A period of treatment therefore in traction at rest in recumbency on a hip frame or (where a certain degree of mobility is required) upon a Thomas bed knee splint, is advisable. Once the diagnosis of tuberculosis has been made then a more absolute method of immobilization must be carried out. The use of a Jones abduction frame which provides pelvic countertraction with control of both lower extremities in extension and a little abduction by skin traction, has proved satisfactory in enabling continued observation to be made of the condition of the hip joint itself and the possibility of controlled activity for other joints of both lower extremities when circumstances permit. As has been mentioned already argument has been held on both sides by those who advocate or condemn the use of absolute and uninterrupted rest in the treatment. Whatever the arguments of a former day it seems clear that, with the availability of effective antibiotic treatment for the constitutional condition and the blood-borne infection relative rather than absolute rest under controlled conditions may come to be accepted more and more as a safe procedure.

It would seem possible that the scope of surgical treatment will become less as further advances are made in antibiotic treatment. At present, it is still necessary to embark on surgery when destruction of articular surfaces has occurred or when the disease has not responded to more conservative methods, or for other reasons. For example, an unsound ankylosis, that is, fusion by fibrous tissue only may give trouble by the development of deformity after prolonged weight-bearing. Furthermore, the stresses and strains upon the fibrous tissue renders possible the dissemination of the disease or the reactivation of it locally from the inclusion in the "healed" lesion of tubercle bacilli.

Arthrodesis of the Hip. This operation was introduced by Russell Hibbs. His method was an extra-articular one and consisted in taking a large graft comprising the great trochanter a neighbouring portion of the neck of the femur and a few inches of the lateral cortex of the femoral shaft. This graft was rotated through 180° and its lower end

buried into the ilium immediately above the acetabulum. This iliofemoral arthrodesis and its modification such as that suggested by Wilson which used a portion of the iliac crest for bridging the gap between the ilium and the femoral shaft produced many excellent results, but had one disadvantage, that in some patients there was a tendency for the graft to pull away from one or other of its attachments as a result of the distraction of increasing adduction deformity. Furthermore, the operation did not give a good opportunity for correcting deformity excepting by opening the hip joint and excising diseased tissue.

Ischio-femoral arthrodesis was first described by Trumble who inserted a graft through the femoral shaft below the trochanter into the ischium and provided extra-articular fusion by a strut which prevented further adduction deformity. It did not, however, provide adequate opportunity for correcting flexion or adduction deformity. For these reasons Brittain introduced his method which involved placing a graft into the ischium through an osteotomy carried out in the inter trochanteric line. After the graft is inserted the femoral shaft is displaced medially under the graft so as to obtain a three point contact; at the same time it permitted adequate correction of all aspects of deformity. These grafts in the presence of a healed tuberculous lesion fused well because of the mechanical distribution of body weight through pressure. It has been noteworthy that the diminution of the mechanical forces of friction and pressure through the hip joint itself has facilitated early bony fusion without any other interference. Kirkaldy-Willis described a method using iliac grafts.

In children there are both advantages and disadvantages in the fusion operation. Of the disadvantages one must note first the tendency for a growing bone to modify its shape according to the stresses that are placed upon it. With the force of body weight lying medially to the hip, however well it is arthrodesed there is a bending effect which is shown by the tendency of all fixed hips in childhood to develop some adduction through architectural re-alignment of bone structure below the arthrodesis. A lesser disadvantage is the possibility of some interference with bone growth through fixation of the upper femoral metaphysis. The advantage of early arthrodesis is the opportunity of earlier ambulation which, apart from the psychological and physical benefits of a return to more normal life, does also minimize the undesirable effects of immobilization. One of the latter defects is premature closure of the epiphyseal growth line in both the femur and tibia at the level of the knee. This may lead to great shortening of the affected limb. It is due not only to immobilization but also to the effects of the resistance exerted from the periphery of splints.

Other Operative Procedures for the Correction of Deformity. Patients with tuberculosis of the hip may be brought for treatment, showing complete bony fusion of the hip joint in a position of deformity (flexion and adduction) serious enough to cause disability. In such cases the strain upon the knee is great and may lead to instability. The benefits of corrective osteotomy are great. Where the amount of destruction and true shortening is not severe, a wedge-shaped intertrochanteric osteotomy will permit a perfect correction. The amount and direction of the wedge should be determined before operation by radiographic measurement. The deformity can be slightly over-corrected by using the mechanics of pelvic tilt in the direction of abduction so as to give a slight increase of apparent length. Nicety of judgement is required in order that the degree of abduction shall not be overdone, for the limb must not be longer than its fellow, which

it will appear to be, when the pelvis is tilted to bring the limb alongside its fellow Such excessive abduction which the surgeon may be tempted to employ in order to compensate for shortening when marked destruction of the joint has occurred, is undesirable, because of the severe stress that is thrown upon the scoliotic lumbar spine that is a result of the pelvic tilt. In spite of these difficulties, judicious correction for adduction and flexion deformity will greatly ameliorate the patient s condition by reducing stress on the knee joint, by giving improvement in length and wider separation of the thighs.

Radical Surgery for Resistant Cases. In those patients not responding to conservative treatment and who therefore have not proved satisfactory candidates for arthrodesis and who both on clinical and laboratory investigations show evidences of continued degeneration there are available two types of excision operation Girdlestone introduced a procedure based upon one which he used in dealing with secondary infection of severe type. In this he detached the gluteal muscles from the great trochanter excised the head and neck of the femur and left a wide opening through which pyogenic material could be evacuated In his more formal excision of the hip joint for tuberculous of the type we are considering, the great trochanter and its muscular attachments were left undisturbed but the head and neck were excised and the acetabulum excavated. This was followed by prolonged conservative treatment in an open-air Hospital unit.

Bankart s excision was the development of earlier attempts to excise the hip joint (first performed by Lewis Sayre) and involved not only excision of the head of the femur and all infected soft tissue but also removed the acetabulum by wide osteotomy through the ilium and ischium above and behind, and through the pubis in front. Both these operations had a certain measure of success. Both involved considerable shortening of the limb yet in those patients who did well, a certain amount of movement was restored and the stability after a prolonged period in weight-relieving calipers, was surprisingly good.

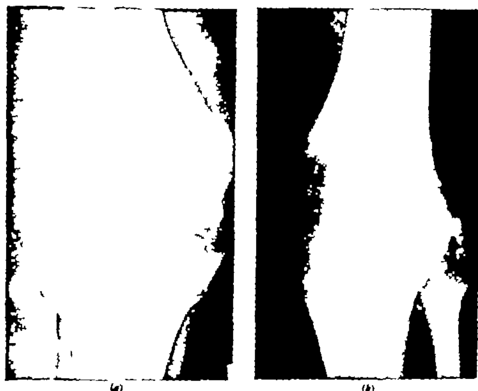
Treatment of Extra-articular Foci. Curettage or excision of these lesions has occasionally been satisfactory but the possibility of intra-articular disease should be borne in mind. This applies particularly to the great trochanter where certain infections have in the past been noted as commencing in the sub-gluteal bursa with involvement of the subjacent bone secondarily Excision of the great trochanter and of all diseased tissue has a place in treatment.

Sinuses should be prevented. When they have occurred they may heal spontaneously if the focus from which they arise is treated properly Their persistence may indicate the presence of necrotic material with or without secondary pyogenic infection. The prevention of the latter requires careful asepsis in the dressing of the sinuses. The use of aniline dyes to paint the opening of sinus tracks has been advocated. When secondary infection or sequestra are present it may be advisable to open up or excise the sinus tracks and to remove dead tissue while the patient s general infective state is treated by the appropriate antibiotic drugs. The tuberculous focus must be treated adequately by the conservative measures already outlined. Before any operative treatment upon sinuses valuable information of their extent may be gained by *sinograms* i.e. radiography after the infection into the tracks of radio-opaque iodized oil.

Tuberculosis of the Knee Joint

Infection of this joint may occur at any age and follows the pattern of incidence seen in the hip joint. Invasion of the joint appears to be through early involvement of the

synovial membrane the characteristic velvety appearance of which with discrete tubercles has already been described. The marginal invasion of the condylar surfaces by granulation tissue and the erosion of the articular cartilage not exposed to major friction leads eventually to impairment of the blood supply of these areas and the formation of necrotic masses which on opposite sides of the articulation are in contact and are picturesquely described as "kissing" sequestra. This is the picture of an advanced disease which may



(a) (b)

FIG. 182. (a) Active tuberculous arthritis of knee showing typical marginal erosions. (b) Condition twelve months after arthrodesis following antibiotic treatment.

(From "Modern Trends in Orthopaedics" (Second Series)
Edited by Sir Harry Platt. Butterworth & Co (Publishers), Ltd.)

also show deep abscess cavities within the femoral or tibial condyles. The disease may start as a purely endosteal focus in the epiphyseal or metaphyseal areas, it may spread into the synovial tissues or remain as a discrete bone focus. Abscesses from such foci may even appear superficially through the quadriceps muscle

Under modern conditions when much greater care is taken of the early phases of articular disorder the common presenting lesion is one of spontaneous and perhaps recurrent effusion into the synovial cavity The diagnosis before any bone damage is apparent may be difficult. Traumatic effusion the result of internal derangement and rheumatoid arthritis must be prominently in mind. In infancy congenital syphilis, low grade osteomyelitis, are to be considered in later childhood trauma, Still's disease and osteochondritis dissecans in adult life recurrent internal derangement, rheumatoid arthritis and early osteoarthritis. These are common problems, but malignant bone

tumours in the region of the knee joint, hæmophilia, gonorrhœa and more obscure forms of arthrosis must be borne in mind.

Aspiration or biopsy as in the case of the hip joint are important diagnostic procedures. There is also a special value in gland biopsy and for this purpose a lymph node is removed from the femoral canal.

Treatment of the Tuberculous Knee Even before the diagnosis is confirmed the limb should be supported upon a Thomas bed knee splint with skin traction applied to the end of the splint and the apparatus suspended. When the diagnosis is confirmed or before, if it is reasonably assured, a full course of antibiotics should be started as previously described. Careful check of the progress will be maintained by repeated radiographic studies at six weekly intervals and by observation of the course of the erythrocyte sedimentation rate (E.S.R.). Three months at least should be devoted to this course. If then the synovial swelling and all other signs of inflammation have subsided and the laboratory evidence is satisfactory graduated activity may be commenced by attaching to the splint a Pierson hinged appliance and a controlled range of movement allowed for a few minutes several times a day If after a week there is no sign of local reaction and the temperature chart remains normal then the range and amount of movement is steadily increased. At the end of one month the E.S R. should be repeated and if normal some movement may be allowed off the splint and the patient graduated to the immersion pool. Two or three weeks later the laboratory tests, including X-ray being normal, a walking caliper splint is provided to take the weight of the trunk from the tuberosity of the ischium. Throughout the whole period streptomycin will have been administered with Para-amino salicylic acid. The former will now be discontinued and P.A.S. with Izoniazid will be continued for a further three months at the end of which time the caliper may gradually be discarded.

In cases in which this favourable course has not occurred and in which bony destruction has already occurred, complete immobilization may be required for at least a further three months, but this can usually be associated with general activity by treating the affected limb in a long leg plaster supported in a weight relieving caliper splint. Arthrodesis of the knee will be the safest insurance against later breakdown (for details of this see p 263) Whether there is a place for synovectomy alone without arthrodesis is still an open question. If it should prove to be a safe procedure when combined with intensive antibiotic treatment, it may thus be possible to restore a useful range of movement.

Tuberculosis of the Ankle and Tarsus

This is not so common as tuberculosis of the knee joint, but the problems and methods are similar In the differential diagnosis repeated sprains, recurrent subluxation of the talus, chronic infective arthritis are the special lesions to be considered.

In treatment a period of bed rest for the general constitutional state with appropriate antibiotics is followed the limb being immobilized in a long leg plaster which extends from the groin to the toes, the knee being slightly flexed and the ankle at a right angle or slightly lower in female patients.

In cases with advanced disease arthrodesis will be indicated after adequate general treatment.

In the tarsal bones (and occasionally in the metatarsals) tuberculosis is more commonly found in children. It is a rare occurrence nevertheless. It is possible here to

synovial membrane the characteristic velvety appearance of which with discrete tubercles has already been described. The marginal invasion of the condylar surfaces by granulation tissue and the erosion of the articular cartilage not exposed to major friction leads eventually to impairment of the blood supply of these areas and the formation of necrotic masses which on opposite sides of the articulation are in contact and are picturesquely described as "kissing" sequestra. This is the picture of an advanced disease which may



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extirpate some of these endosteal lesions by surgical curettage during the course of antibiotic treatment and for some cases arthrodesis of individual joints after excision of the infected material is satisfactory

Tuberculous Teno-synovitis in the Foot

This disease is less common in the foot than in the hand. It may affect the tendon sheaths, particularly the peroneals, as an isolated lesion or it may affect the tendon sheaths in association with neighbouring joint disease of which it may be the first sign. In this it resembles the similar and much commoner tenosynovitis in the hand to the discussion of which the reader is referred (p. 322).

Tuberculosis of the Shoulder

Compared with tuberculosis in the areas already discussed the disease is uncommon in the shoulder It does, however have some peculiar features. In infancy it tends to assume a fulminating character and is predominantly synovial in type the rapidity of evolution and the granulomatous character of the lesion makes important the diffential diagnosis from sarcoma or osteomyelitis. In adults, particularly in the elderly a slow crumbling type of bony destruction with little synovial reaction has given rise to the title *caries sicca*. Yet in other adult patients the disease may resemble tuberculous disease elsewhere in its abscess formation etc. Tuberculosis must be distinguished from the more common chronic lesions of the shoulder particularly those giving rise to pain, stiffness and bone atrophy e.g. pericapsular fibrosis and bursitis—the frozen shoulder

Radiologically the infantile form shows articular components which are much reduced in density by vascular osteo-porosis with little, if any sign of bony destruction. It must be remembered that the radiographs cannot show the cartilagenous destruction, which may develop to some extent before any bony involvement is apparent. In caries sicca the general bone densities may not for some time be greatly affected Any lesion causing erosion of the articular cortex of the humerus or cavitation of the humeral head or glenoid areas of the scapula should be regarded with suspicion. The diagnosis should be confirmed by biopsy and the patient should be admitted to a special orthopædic unit or sanatorium for this, but also for the period of general investigation and treatment that is required for all tuberculous illnesses.

Treatment. Rest for the shoulder joint itself can only properly be given by the use of a plaster of Paris splint or spica. No mechanical form of splinting can function efficiently with comfort. The plaster splint should be in the form of a jacket encasing the trunk and taking a firm hold upon the pelvis and having an extension on to the upper extremity down to the wrist which will hold the shoulder at approximately 45° abducted, and the elbow slightly forward of the coronal plane of the body the elbow should be flexed at approximately 90° Some surgeons emphasize that the shoulder should be slightly externally rotated. This should not be overdone. In infantile tuberculosis immobilization and treatment is upon general lines as already discussed. Because of the difficulty (except by looking into the joint) of knowing to what extent cartilagenous destruction has occurred the prognosis for the restoration of movement must be very guarded until the progress has been studied by serial radiographs etc. over a period of at least two years.

In adults and older children if destruction occurs in the articular surfaces, arthrodesis of the joint is generally necessary when the disease has become quiescent. In this operation

the joint is widely opened up as described on page 253 then all obviously diseased tissue is excised, the remains of the articular cartilage and underlying cortical bone is removed from both the head of the humerus and the glenoid cavity From the periphery of the latter the *labrum glenoidale* is excised and the under surface of the acromion and lateral surface of the great tuberosity are freshened. Good coaptation of the surfaces



(*a*)



(*b*)

FIG. 183 (*a*) Gross disease of the head and upper end of the humerus, proven tuberculous. Treated by immobilization and streptomycin. (*b*) Condition more than two years later—almost complete reconstruction. Full movement.

(From "Modern Trends in Orthopaedics" (Second Series). Edited by Sir Harry Platt, Butterworth & Co. (Publishers), Ltd.)

being obtained the bones are held together at an angle of approximately 45° by transfixion with a short Smith-Petersen trifin nail which is left *in position for three months* until fusion has occurred. During this time the arm is supported in a plaster of Paris spica and antibiotic treatment is continued.

An alternative method is that described by Brittain in which an entirely extra-articular posterior approach is used and a graft inserted between the humeral neck and the axillary

border of the scapula immediately below the glenoid. It has the disadvantage that the intermediate section of the graft has no bony contact and it may be absorbed. Furthermore with the availability of antibiotic control there is no point in avoiding the excision of diseased tissue.

Tuberculosis of the Elbow

As with tuberculosis of the shoulder so in the elbow the disease is often insidious in its development and is liable to produce a considerable intra-articular abscess which expands to ensheath the joint before there is much evidence of bony destruction. In the earlier phases the disease is to be distinguished from "tennis" elbow the pain of which is characteristically localized on the outer side, is related to particular movements and has no swelling from rheumatoid arthritis, which generally affects other joints as well from osteochondritis of the capitellum in young patients, where swelling is associated with a characteristic radiograph of fragmentation in the ossific nucleus from traumatic fibrositis ossificans, where the history of trauma and the radiograph is distinctive from osteoarthritis of the elbow such as may follow fractures and other injuries in earlier life, and which may have loose bodies causing incidents of locking or may have some degree of ulnar neuritis.

If the patient comes late for treatment or if in spite of antibiotic treatment, there is destruction of the articular surfaces, arthrodesis of the joint is the treatment when the disease is quiescent. The preparation of the bone surfaces of the humerus and sigmoid fossa of the ulna is accompanied by excision of the head of the radius so as to preserve pronation and supination movements of the forearm. The joint is held at an angle of rather more than a right angle until fusion is sound. In the non-operative and late post operative treatment this joint is one which is suitable for the use of blocked leather moulded splints.

Tuberculosis of the Wrist

Tuberculosis of the wrist and carpal joints may be secondary to tendon sheath infections. As an isolated lesion it is to be distinguished from rheumatoid arthritis in which it may be the first joint to be affected. At an early stage it may be extremely difficult to make the distinction on clinical and radiological grounds, for the appearances can be identical biopsy may be required Among the other lesions to be considered are chronic occupational tenosynovitis, mal-united Colles fracture, osteoarthritis of the wrist joint following injuries particularly scaphoid fractures, and lunate malacia, Sudek's post traumatic lesion, osteomyelitis of the lower end of the radius and polycystic disease of the carpus. The disease tends to respond well to rest and antibiotic drugs but if destruction of the articular surfaces has taken place it may be necessary to perform arthrodesis. Here operative treatment of the radial and carpal joint surfaces is associated with excision of the lower end of the ulna.

Tuberculous Tenosynovitis in the Hand

This may affect either the extensor or flexor tendon sheaths more commonly the latter giving rise to what used to be called the *compound palmar ganglion* in which the common sheath in front of the wrist is affected with its extensions upward into the forearm and downwards into the hand. A single finger sheath may be affected in particular the index, ring or middle fingers, because these do not communicate with the common sheath. The disease may affect those who receive cuts and minor abrasions on

the fingers while handling tuberculous material, e.g. butchers and cow men, but other people may show the disease as a blood-borne infection. The disease takes a chronic course and there is a great liability to secondary pyogenic infection if the disease goes unrecognized and the patient receives other breakages of the skin surface

Pathology The tendon sheath is distended with a turbid serous fluid and may contain fibrinous "melon seed" bodies, caseous material and typical tuberculous granulation tissue the tendons may become thinned out and may even rupture.

In the *diagnosis* the disease will naturally be suspected when the signs of the chronic tendon sheath lesion are found in one of the workers mentioned. Then it is more likely to be found amongst men. In women it is to be considered with rheumatoid arthritis which is more common in them and which often arises in one finger as a spindle shaped, painful swelling of an interphalangeal joint, but which also may show itself as a chronic tenosynovitis affecting especially the flexor sheaths in the palm with nodular thickenings in front of the metacarpal necks. Other signs of tuberculosis will be looked for but the E.S.R. will not be very helpful, for in both diseases it may well be raised.

The tuberculous lesion is also to be distinguished from other (generally occupational) forms of tenosynovitis. These particularly are liable to affect the abductor sheaths of the wrist and thumb above the wrist which are less liable to be involved in tuberculosis The characteristic "sandpaper" friction is not found in tuberculosis, but in late forms of the latter there may be a different type of crepitus due to the formation of fibrinous "melon seed" bodies.

Primary septic tendon sheath infections should cause no diagnostic difficulty the history of a septic wound of a finger pulp or whitlow with the acute local and general manifestations of these conditions should be perfectly clear

Treatment should be by total excision of the affected tendon sheath and the surgeon should follow precisely the rules, now customary in hand surgery of avoiding longitudinal palmar incisions. Retinacular bands should, wherever possible, be preserved, particularly where bow stringing may result if they are destroyed. Post operative rest of the wrist in plaster or other moulded splint should be retained for two or three months. Although theoretically the fingers affected should also be splinted, it is advisable to allow some movement for them. This treatment should be accompanied by full antibiotic control as in other tuberculous lesions.

Complications

Rupture of the weakened tendons may occur following infiltration of their substance by granulation tissue. Some success has been reported from the use of free tendon grafts, in particular for the replacement of flexor digitorum profundus.

The neighbouring joints may become involved by direct spread. The wrist and metacarpal joints are particularly vulnerable and if sinuses form, these may become secondarily infected with the production of an extremely serious disability The hand becomes massively swollen and oedematous, pus may ooze from many sinuses, the radiographs may show a much osteoporotic bony structure with apparent loss of joint outlines and there may be many small ill-defined sequestra. It is easy to come to the conclusion that salvage is impossible and that amputation is necessary yet with attention to first surgical principles much may be done to achieve a useful hand The free opening of the abscess cavities, with clearance of necrotic material, immobilization in plaster moulds

and full antibiotic treatment, may result in a remarkable degree of restoration with a useful hand even though it may be necessary to provide some semi-permanent removable splint for the wrist such as that made of blocked leather or plastic acrylic material.

Tuberculous Dactylitis is now rarely seen in Great Britain. It causes cystic destruction of the shafts of the phalanges and metacarpals, involvement of the intervening joints and a liability to sinus formation and secondary infection. At first the condition may be mistaken for other cystic diseases including enchondromata because of the expansion which occurs in the affected bones. The disease normally is part of a generalized tuberculous process with other manifestations of the disease. The patient being in an extremely neglected, unhygienic condition in fact scrofulous

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CHAPTER X

HÆMATOGENOUS OSTEOMYELITIS AND SEPTIC ARTHRITIS

NORMAN CAPENER

OSTEOMYELITIS

As commonly seen, acute hæmatogenous osteomyelitis is a general systemic infection with focal pyæmic lesions in the bones, skin and other soft tissues. It is more particularly a disease of childhood but is occasionally found in adults. The commonest organism responsible is the *staphylococcus pyogenes aureus* Occasionally streptococcal infections are found and this is relatively more common, though not absolutely so, in infants. Other bacterial infections of particular note are those of typhoid and actinomycosis.

The importance of the disease is due to the severity of the lesions in bone occasioned by its anatomical and physical peculiarities its structure and blood supply As in other general infections, the invasion of the body by pathogenic organisms and their circulation in the blood stream is not the full explanation of the development of a disease in which there would seem to be a breakdown of body defences and thus a "prepared soil." Injury has often been regarded as a factor in osteomyelitis because the disease affects boys predominantly and the bones of the lower extremity more frequently Certainly the susceptibility to injury though probably commoner in boys, is a general feature of childhood. The dynamic stresses borne by the infantile skeleton are greatly out of proportion to the weight of the child the vulnerability of bone is particularly found at the metaphyses. If to injury is added the presence of organisms circulating in the blood stream, there must also be a general constitutional defect causing a temporary breakdown of antibody defences. Osteomyelitis used to be regarded as a disease peculiar more or less to the poorer strata of society in which hygiene was defective, but the disease is by no means thus limited. Furthermore a seasonal incidence is sometimes to be noticed, particularly in the winter months.

Pathology In an earlier section we have already dealt with the structural peculiarities of growing bone which will explain much of the special morbid anatomy of osteomyelitis the vascular supply by a diaphysial nutrient vessel, the surface supply through the periosteum of the bony cortex and the periarticular arterial circle of William Hunter which surrounds the ends of the bones and supplies branches to the epiphyses and metaphyses. The important relation of these vessels and of the metaphyses themselves to synovial reflections accounts for the ease with which certain joints are affected secondarily and at an early state by direct spread from a neighbouring bony focus While to a certain extent anastomosis occurs between the smaller arteries it happens that, if there is occlusion of the major radicles, revascularization of the area affected is difficult and necrosis tends to occur In the past there was controversy concerning the primary site of infection There is little doubt that infection may reach the bone through any of the normal vascular channels, but in British experience the metaphyseal focus appears to be the commonest.

The arrival of organisms in the vascular channels of the metaphysis may be by small emboli or by the infection of a hæmatoma the result of previous injury. Whatever the nature of the initial focus there are two sequelæ of widely destructive nature (1) the production of an inflammatory exudate which causes a rise of intra-osseous pressure and obstruction to the venous return (2) thrombosis of the veins which completes the vascular interruption, with bony necrosis as its result. The extent of the necrosis is dependent upon the severity of intra-osseus pressure and upon the degree to which larger

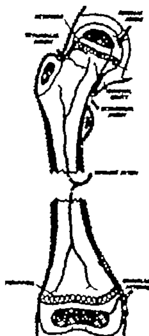


FIG. 184. Diagrammatic representation of femoral metaphyses, their blood supply and their relation to joint cavities.
(*Courtesy of British Medical Journal*)



FIG. 185. Diagram showing the influence of spreading zones of intra-osseous pressure *arising from central abscess (black circle)*. Arrows indicate penetration of metaphyseal cortex into synovial cavity or diaphyseal spread. Compared with Fig. 184 it will be noted that vascular obstruction by such an abscess may cause epiphyseal necrosis (*indicated in black*).

blood vessels are obstructed. The natural relief of intra-osseous pressure occurs as the necrosis or bone absorption in the neighbourhood of the thinner cortex of the metaphysis, permits pus to escape under the periosteum. This may occur early to such an extent as to limit considerably the diaphysial necrosis. In this event pus tracks along the shaft of the bone under its periosteum, lifting this away from the bone itself, and thus leads to subsequent interference with the vascular supply of the superficial part of the cortex, which may then suffer necrosis and superficial flaky sequestration. This type of lesion may occur independently through primary involvement of the periosteal blood vessels without medullary or metaphyseal involvement.

The essential changes, then, are inflammatory exudation, rise of intra-osseous pressure, vascular interruption and thrombosis. The foci from which organisms reach the blood stream may be in the tonsils or in the skin. In infants the infection may arise from post-natal lesions of the umbilicus or from the alimentary tract during breast feeding from maternal mastitis.

The manifestations of osteomyelitis vary from the fulminating type of great severity to the almost silent chronic stage without acute symptoms or signs. In the latter the onset of the disease may occur years before there are clinical manifestations One of the best known of this type of case is that described originally by Brodie where a densely walled abscess cavity in the metaphyseal end of the shaft of a long bone may give rise to chronic symptoms and occasionally result in radiographic appearances which have to be distinguished from true bone cysts or neoplastic conditions Another chronic type of osteomyelitis was that described by Garré as *chronic sclerosing osteitis* which, as implied by its name is a rather more diffuse process with sclerotic changes and this may give rise to similar chronic symptoms which must be distinguished on the one hand from a syphilitic process and on the other from Jaffé's *osteoid osteoma*

Apart from the two forms just mentioned chronic osteomyelitis may result from infections of the common acute type. As already described the pathological processes involve necrosis This necrosis, being dependent upon the extent of the vascular occlusion, causes *sequestration* of larger or smaller sections of the diaphysis. Where the periosteum is elevated on the surface of an abscess containing such sequestra, new periosteal bone is formed, providing in extreme cases an *involucrum* The rupture or opening of abscesses through this involucrum provides a *cloaca* through which pus may be discharged on to the surface through a *sinus* These are the classical appearances which with efficient primary treatment should not occur In modern times minor changes of similar type may occasionally appear but when present suggest that treatment has been faulty The imperfect application of antibiotic treatment without adequate surgery may result in such changes but also tends to produce peculiar lesions of chronic granulomatous type without clear sequestration but with bony enlargement and superficial osteogenic reactions providing radiological appearances which must occasionally cause difficulty in diagnosis from neoplastic conditions.

The Clinical Picture The fact that a patient may have a single focus of bone or joint infection should not cause the surgeon to overlook the general constitutional disease, which, though never trivial, can be so serious as to mask local signs and to mimic other important general diseases such as acute rheumatism, poliomyelitis, and meningitis. It is essential that osteomyelitis should be considered in the differential diagnosis in any child with an acute generalized infection, particularly if there are one or more of the following signs pain and tenderness in a limb, particularly in relation to the long bones or in the neighbourhood of joints swelling of or near joints weakness and even paralysis of a limb or muscle spasm or loss of movement in one or more joints. It should be remembered that symptoms may be referred far from the site of the disease and that the general toxic state of the patient may by mimicry mask its real nature.

Treatment. Upon the extent to which the blood vessels are obstructed and the tissues devitalized is dependent the failure or imperfections of antibiotic treatment. It should be noted that in the early stages when correct treatment is most important, radiographic examination is of no help. In fact there is no practical way of knowing at this stage of treatment the precise extent or intensity of the vascular occlusion. These circumstances must influence judgement upon the need for surgical intervention firstly for diagnosis and secondly for treatment.

The aim should be to control the general constitutional disorder and to prevent the mechanical effects of vascular interruption and inflammatory exudation. This can only

be achieved in the first few days of the disease by adequate maintenance of the appropriate antibiotic level in the blood stream, and this can only be determined by bacteriological studies and for this blood culture is of the greatest value. The absorption of the toxic products into the general circulation is prevented physiologically by splintage. These measures must be applied with the greatest efficiency from the onset. In those cases in which, after twenty-four hours, severe pain, tenderness and an unsettled temperature continue, decompression of the affected bone must be carried out. The antibiotic sensitivity of the invading organisms, if not already determined by blood culture, should be checked, if possible by aspiration or by opening the bone. Not more than three days should be allowed to elapse with an unsatisfactory response to conservative measures, before embarking upon surgery If the organism is sensitive to penicillin, and in all cases before this is determined, penicillin should be given in the amounts recommended by Garrod that is, in children up to 50 000 units four hourly Alternatively one quarter million units of crystalline penicillin twice a day Some workers have given much larger doses amounting to one million or more units a day but there would appear to be no special advantages in this large dosage and care must be taken to avoid this in an attempt to deal with the situation where, through avascularity the disease is not being brought under control as it should be by a surgical approach. As with any acute infective process care must be taken to maintain tissue fluid electrolyte balance. When surgery is necessary *it must always be associated with physiological control under conditions which permit* of ready observation of the affected area. Thus in the lower extremity the use of a Thomas bed-knee splint or in the case of lesions of the hip joint treatment upon a Jones abduction frame or a split plaster spica is advisable.

Surgical Treatment of Osteomyelitis. In the acute phase the essential treatment is decompression of the lesion, not drainage though the latter may be an incidental mechanical result of decompression. Having decided upon the site of the disease, the surgeon should explore it by an approach through anatomical intermuscular planes and, wherever possible, the opening made into the bone should be at a point where it will be covered afterwards by vascular muscle. If an abscess is found under the periosteum, exploration should not cease there but should be continued by openings into the metaphysis or into the medullary cavity Such openings which usually will be at least two in number should be sufficiently large for the insertion of a small catheter for irrigation at the time of operation, and so that it is less likely to be blocked prematurely by blood clot. Having taken material for culture and after washing out the abscess with normal saline and instilling penicillin into the depths of the abscess cavity the surface wound is completely closed. Thereafter the limb is supported and elevated upon a suitable splint and further antibiotic treatment is given. Suggestions for the exposure of long bones have already been given. In the lower extremity posterior approaches to both the femur and the tibia are strongly advised. In the case of the femur because there is less risk of damage to muscles and nerves, and in the tibia so as to avoid its subcutaneous surface In both *approaches drainage, should it occur is dependent and the scars heal better than those* placed anteriorly

With efficient antibiotic treatment, examples of the extensive chronic disease which formerly provided such a large and distressing feature of orthopædic surgical practice, have become rare. Patients treated before the antibiotic era still occasionally appear and so also do a few who have been imperfectly treated with antibiotics. Here radical

measures may be necessary The principles are the excision of scar tissue and sinus tracks, the opening of bony cavities by removing sufficient cortex to explore the whole length of a central bone abscess and to leave a gutter after the removal of sequestra. Where possible such cavities should be eliminated by inserting vascularized muscular flaps.

Where cavities lie close to the surface and cannot be closed by muscular flaps, as on the subcutaneous surface of the tibia, the use of skin grafts following the excision of infected tissue, has been shown to be satisfactory by the experience of chronic osteitis complicating war wounds. This in the first instance may be by free split grafts and later by transfer of a flap graft from the opposite leg.

Complications of Osteomyelitis. The complications include pyæmia, septicæmia, septic arthritis, myocardial lesions, pericarditis, pyonephrosis and, following chronic infection with sinuses of long duration, amyloid disease. A local complication is *pathological fracture* and though bound to become less frequent under modern conditions it still occurs and is more likely to do so where successful treatment by antibiotic drugs has for various reasons been incomplete. In the past the surgical procedure of *saucerization*, applied to the process of cavity obliteration after sequestrectomy has lead to error Not infrequently when this has been done the affected bone was not able to withstand normal stress. The amount of living bone removed from a diaphysis should leave a deep *gutter* rather than a shallow *saucer* Care should be exercised in the use of surgical tools, for a fracture may be started by a fissure or notch left on a cortical edge and this may be sufficient under repetitive movement to lead to a complete fracture. In the old days before the introduction of antibiotics, Capener and Pierce in 1932 reporting upon 1086 cases of osteomyelitis, found pathological fractures in 1 6 per cent of them.

Another remote complication of chronic osteomyelitis is the development in the scar of squamous celled carcinoma. The subject was reviewed by Gillis and Lee based upon their work for war pensioners. Although any scar may develop carcinoma there appears an added liability in the wounds which remain open and drain pus for many years. This sequel must be borne in mind, not only in the chronic sinuses and ulcers of war wounds, but also in cases of chronic hæmatogenous osteomyelitis.

Secondary infection with saprophytic organisms of the pyocyaneus, proteus, diphtheroid types may also be found in chronic sinus tracts. Precise surgical excision of infected areas and necrotic tissue and the closure of cavities is important.

Septic Arthritis

Acute Suppurative Arthritis due to infection by pyogenic organisms may occur in the following ways (*a*) as a blood-borne infection, (*b*) by direct spread from a neighbouring bone focus of hæmatogenous osteomyelitis, (*c*) by lymphatic spread from neighbouring soft tissue infections, e.g. those arising from skin abrasions in the hand, foot or knee, (*d*) by direct involvement in penetrating wounds and open fractures, (*e*) by secondary infection of tuberculous or other chronic joint disease.

(*a*) Septic Arthritis of Hæmatogenous Origin. This is a manifestation of some form of septicæmia though the latter may not be obvious. The organisms most likely to be responsible are the streptococcus the pneumococcus or the gonococcus. Usually one or several rather than many joints are affected.

The clinical appearances closely resemble those of acute osteomyelitis with a single

focus but though in the latter the site of the lesion may on close examination, be found to be at the articular end of one bone, in septic arthritis the signs in the joint itself are clearer While, therefore the patient may be severely ill and with all the constitutional signs that one would expect, the part affected will be held rigidly immobilized by muscle spasm and the joint itself will be swollen, hot and tender The skin over it may well be reddened and the swelling will tend to be limited to the normal anatomical confines of the capsule and synovial tissues. If uncontrolled, the muscle spasm which causes the rigidity will tend to produce contractures and vicious postures which, by the action of the stronger muscles aided by the influence of gravity and associated with the weakening of the capsular and ligamentous elements, will lead to deformity and subluxation or dislocation.

The diagnosis which will be suggested by the physical signs should be confirmed at once by aspiration of the joint and bacteriological investigation. The gross appearance of the fluid may itself give broad confirmation of the nature of the problem, but specific treatment may not be satisfactorily settled until the antibiotic sensitivity of the invading organisms has been determined.

Treatment. After aspiration of the joint the limb must be supported in a physiological position. This has been broadly discussed in the previous section upon "Physiological Control" In the upper extremity divided plaster of Paris moulds are generally satisfactory splints. In the lower extremity elevation of the limb on a splint through which traction can be applied and which still permits visual examination, is better

Repeated aspirations are necessary to relieve tension in the joint but should not be done more than is necessary for this and for the instillation of the appropriate antibiotic. As compared with osteomyelitis a higher proportion of the infections are due to streptococcal and other pyogenic organisms rather than to the staphylococcus aureus. Therefore until the exact bacteriology has been determined it is appropriate to administer penicillin. This should be given parenterally in the amounts as generally used it should also be introduced into the affected joint where because of its large molecular structure, penicillin remains in relatively high concentration for several days afterwards.

When the infection has been brought under control and the temperature has become normal for five days, movement is commenced under precisely regulated conditions. Mobilizing devices may be added to the splints so that a small range of activity with support may be graduated in amount and frequency with appropriate stimulus to muscular function.

(*b*) Involvement from Neighbouring Osteomyelitis. Where there is an acute infective lesion of bone in the neighbourhood of a joint the latter may take part in the inflammatory process in the area without itself becoming infected. In other words local hyperæmia may result in a swelling of the joint through the development of a synovial effusion just as the extraperiosteal tissues will show œdema Where a metaphyseal lesion of osteomyelitis lies within the area covered by a synovial cavity then direct spread can occur by break through from the bone into the synovial tissues. It is, therefore, important for diagnostic, as well as for therapeutic reasons, to aspirate all joint effusions in such cases, whether apparently infected or not the relief of mechanical tension is as necessary as the determination of the nature of the infection. Nevertheless the principle of treatment must be to deal with the bony focus.

Special problems in the hip infected from osteomyelitis of the femoral neck, are separation of the capital epiphysis and pathological dislocation Both are caused by faulty

treatment first of the underlying infection, and secondly of the control of the limb Unless properly splinted with traction in a physiological position uncontrolled muscle spasm will direct the femoral shaft into the vicious position of flexion and adduction, and so facilitate the development of either condition both of which may be still further complicated by massive avascular necrosis of the femoral head.

If detected soon these disasters can be mitigated by reduction in traction, and correct treatment for the septic process. If not recognized they will lead to severe deformity and shortening of the limb even though the infection may eventually be brought under control. In days gone by such sequelæ of septic arthritis of the hip joint were amongst the most tragic problems of bone and joint surgery for without antibiotic measures, they lead to prolonged suppuration with multiple draining sinuses and eventual death from amyloid disease.

(c) Lymphatic Spread The importance of this type of lesion is in the recognition of its possibility in monarticular infections and therefore of the need always to search for possible primary foci in the lymphatic area to which the joint belongs for example abrasions of the skin in peripheral parts of a limb trophic sores in vascular or neurological disease and, particularly in the case of the hip joint, infective lesions of the external genitalia and buttocks. A special type of this lymphatic spread may be found in septic arthritis of the cervical vertebral joints as a complication of acute tonsillar infections and which may lead to cervical subluxation.

(*d*) Open Wounds. In penetrating wounds or fractures with wounds leading into joints, efficient primary treatment according to first principles should prevent this serious complication. The aim should be the thorough cleansing of wounds, the excision of devitalized and contaminated tissues, the local use of antibiotics and the conversion of the open wound into a clean closed one and further treatment as for any other potentially infected joint.

(*e*) Secondary Infection Amongst the most serious diseases of joints in the past has been that of pyogenic secondary infection of tuberculous joints.

Most often the secondary organisms gain entrance from the surface of the body through sinus tracks resulting from the rupture or surgical incision of a cold abscess arising from the tuberculous joint. The invasive process may occur suddenly or insidiously but in either case leads to a profound aggravation of the constitutional disease. A high temperature with sweating and fluid loss, emaciation and general increasing debility lead to amyloid disease and early death. Such commonly occurred in the pre-antibiotic era and was responsible for the extreme care taken to prevent sinus formation in tuberculous disease by the application of the conservative measures discussed in the special section upon tuberculous joints. Now in such cases, the same care is taken but it is possible, and in fact advisable, to perform surgical operations to deal with secondarily infected lesions after the bacteriological character of the infection have been determined. The exposure and excision of necrotic tissue and the administration of the appropriate antibiotic drugs with the most careful immobilization of affected joints is practised.

CHAPTER XI

TUMOURS OF BONE

A. L. Eyre Brook, with the assistance of C. H. G. Price

This section will present the tumours, both benign and malignant, occurring in the skeleton including those arising in bone, cartilage, fibrous tissue, fat, reticulo-endothelial, and hæmopoietic tissues found within its confines. Great difficulty has always been found in classifying bone tumours: the subject is complex and the comparative rarity of most bone tumours renders the personal experience of any one surgeon far from great. No single factor has done more to assist the clarification of the subject than the organization in 1921 of the Registry of Bone Sarcoma, by E. A. Codman, under the ægis of the American College of Surgeons: a very large collection of fully documented and authenticated cases has since been collected and has provided the material for study by innumerable pathologists and surgeons, helping to produce order out of a subject very prone to relapse into chaos. Similar registries have been started in many centres in this country and elsewhere. Many of the descriptions given in this section, and most of the illustrations presented, have been derived from the collected records of the Bristol Bone Tumour Register (1946–1956). The data relating to sex, site, and age distribution have been derived partly from the same source, and from other large series published elsewhere.

Too precise a classification resulting in innumerable sub-groups is probably controversial and of much less practical value to surgeons than one broadly based and accepting the mutability of certain cells in bone—fibroblasts, chondroblasts, osteoclasts, and osteoblasts—as stressed by Willis, and more recently by J. J. Pritchard.

Whilst osteogenic sarcoma was a term at one time applied to all sarcomata originating in bone and derived from the truly skeletal tissues, there is now an acceptance by many of a greater differentiation into osteosarcoma, chondrosarcoma, and fibrosarcoma, as there are clinical and prognostic features as well as histopathological features to support such a separation.

The difficulties in classification are not confined to the malignant connective tissue tumours: the osteoclastoma or giant cell tumour presents a very similar, or identical, appearance to "myeloid" epulis or the brown tumour of hyperparathyroidism; but here again, Willis (1953) reminds us that resemblance does not of necessity denote identity and that similarity between neoplastic and non-neoplastic tissue is even better seen in chondroma and normal cartilage, or "some areas in osteosarcoma" and "osteoid tissue of healing callus." This is, indeed, one of the occasions to stress the need for a *broad basis of diagnosis* based on clinical, radiological, and histological features, and to acknowledge that certainty in diagnosis can only derive from a complete agreement of the verdicts given after careful examination of all relevant material by the clinician, pathologist, and radiologist. The lack of unanimity after discussion by an experienced team of three members so assorted is an indication for re-investigation of the lesion under review: even so, it may be expected that some 10 per cent of all cases will be of a questionable nature and on these no certain diagnosis can be fully acceptable.

A further difficulty arises over the benign tumours of bone which, when multiple, present the well known picture of Keith's aclasis or multiple exostoses, and over those cartilaginous tumours within the bone which, when multiple, give us the clinical picture of dyschondroplasia, enchondromatosis, or Ollier's disease. We must agree with Jacobson (1940) that "typically and essentially however enchondromatosis is a dystrophic and not a neoplastic disease," and this must apply equally to multiple exostoses where Keith's concept of a defect in modelling of the bones appears to explain the bony abnormalities which result. In adopting this view one need not be unduly influenced by the fact that certain cases of both multiple exostoses and enchondromata may eventually show frank neoplasia by sarcomatous transformation of a pre-existing benign "tumour" Neither of these conditions will, therefore, be included in this chapter although the solitary osteochondroma and the chondroma fulfil the criteria required of a neoplasm.

Further difficulties are presented by certain lesions where there still remains doubt as to whether we are dealing with a dystrophy an inflammatory lesion, or a tumour Reference will be made to some of these, although their claim to be included may be slight the reason for this inclusion is that the study of these lesions will be most helpful while we are attempting the differential diagnosis of tumours of bone.

No study of bone tumours is complete without considering secondary growths in bone in some detail, as few cases with a clinical and radiological picture suggestive of malignancy are encountered where the possibility of this being due to a metastasis does not deserve careful consideration.

Classification

Benign

I Arising from bone, cartilage, and fibrous tissue

(1) OSTEOCHONDROMA

(2) BENIGN CHONDROMA

(3) BENIGN CHONDROBLASTOMA (Codman's tumour)

(4) OSTEOID OSTEOMA

(5) NON-OSTEOGENIC FIBROMA

(6) Osteogenic fibroma or Osteoma (ivory)

(7) Chondromyxoid fibroma

II OSTEOCLASTOMA (Some cases)

III. Hæmangioma

IV Adamantinoma

V Subperiosteal Lipoma

Malignant—Primary

I Arising from bone cartilage, or fibrous tissue in bone

(1) OSTEOGENIC SERIES (a) OSTEOSARCOMA

(b) CHONDROSARCOMA—Peripheral and Central

(c) FIBROSARCOMA

(2) Parosteal Fibrosarcoma

II MALIGNANT OSTEOCLASTOMA

III EWING'S SARCOMA (a questionable pathological entity)

IV Arising from Hæmopoietic System

(1) MYELOMA

(2) PRIMARY RETICULUM CELL SARCOMA

V Chordoma

VI. Liposarcoma

VII Angiosarcoma

Malignant—Secondary

I METASTASES from

(1) Carcinoma

(2) Neuroblastoma

(3) Hodgkin's disease

II Local invasion from Synovioma

A useful brief discussion of some of the problems of bone tumour classification (and grading) are given by Robb-Smith (1955).

Osteochondroma

These tumours appear to result from an aberration of the periosteum in producing cartilage which then proceeds to ossify Osteochondromata are most frequently found in persons of the second decade (44 per cent), whilst three-quarters will be found to occur between the ages of 6–25 years. Relatively few are seen in patients over 40 years of age (5 per cent, Stocks and Barrington 1925 15 per cent, Meyerding, 1927). These large published series show an overall male predominance of rather more than three male to two female cases. The following Table gives the site distribution reported by Stocks and Barrington

Site	*Percentage*
Femur	28
Tibia	18
Humerus	13
Pelvis	10
Scapula	8
Foot	6
Fibula	2
Other sites	15

Stocks and Barrington mention that about 10 per cent of the patients included in the series had a family history of other members being afflicted with solitary or multiple exostoses. In their series, six tumours out of five hundred and six underwent sarcomatous changes (1 2 per cent) this figure should be contrasted with the malignancy rate of 11 per cent reported by Jaffe (1943) in a series of twenty-eight cases of Keith's Aclasis. Other figures for malignancy rate in solitary osteochondroma are 2 per cent, Lichtenstein (1952) and 5 per cent, Geschickter and Copeland (1949).

The more common pedunculated osteoma, capped by cartilage, is found growing from the metaphysis, the tumour pointing away from the joint. While usually presenting

as the accidental discovery of a hard lump the osteochondroma may cause pain from interference with the action of overlying tendons or muscles, from which the tip is separated by a bursa. On the inner side of the upper end of the tibia the osteochondroma may so interfere with the action of the tendons of sartorius, gracilis, and semitendinosus



Fig. 186(*a*). SESSILE OSTEOCHONDROMA. B.T.R./161 M aged 19 This shows the precise outline of a benign neoplasm. The cortex and trabeculae are continuous with *the parent bone. This tumour is more sessile* than pedunculated and is situated almost mid-shaft Great variety is possible with this tumour



Fig. 186(*b*). OSTEOCHONDROMA. (H.Ph. & T × 40) B.T.R./845 M aged 15 The illustration shows the manner in which this tumour in a juvenile attempts to mimic the structure of a long bone growth cartilage.

as to cause "locking" of the knee, presenting a clinical picture superficially resembling an internal derangement of the knee joint Very occasionally a fracture of the pedunculated tumour brings its presence to light.

The sessile type of osteochondroma (Fig. 186 (*a*)) is much more variable in appearance, and may contain considerable cartilaginous masses and often attains to much

greater size. This tumour is also found in older children, adolescents, and young adults, common sites being the femur (lower end), the tibia (upper end and lower end), the humerus (upper end), and also the flat bones of the scapula and pelvis. A very typical site is the lower end of the tibia on the outer side, so distorting the fibula as to make the inexperienced certain that one is dealing with a tumour of the fibula. *Slow* growth is more likely to continue in these cases after skeletal maturity but one should regard with suspicion any osteochondroma which shows progressive or rapid growth after the age of 25 years moreover all such specimens must be subjected to histological examination after removal. The larger tumours, when consisting mostly of cartilage, may show some mottling in a radiograph due to calcification in areas of degeneration, an appearance quite distinct from the orderly trabeculation of the bony elements. In the scapula and ilium, the growths usually arise near the vertebral border or iliac crest, in each instance in that part of the blade most recently ossified from cartilage, and in which bone growth is most prolonged. This feature resembles the site distribution of osteochondromata in the long appendicular bones.

A very typical circumscribed osteochondroma arises from the terminal phalanx, usually of the big toe—the subungual exostosis. Capped by cartilage and slow in growth, it usually causes symptoms by displacing the nail and causing pressure in the shoe. The sufferer is most frequently a young girl or woman between the ages of 15 and 40 years. Although occasionally occurring in the hand, the vast majority occur in the foot, and some have suggested trauma as the important factor in the initiation of this growth. Eighty-six cases were reviewed by Stocks and Barrington the toes were involved in seventy-seven cases, and in seventy-six the great toe.

Pathology The section of the osteochondroma (Fig. 186 (*b*)) shows the normal cartilage of the cap passing through orderly endochondral ossification, as seen in a typical epiphyseal growth cartilage In the stalked type, the tumour consists largely of this bone but in many sessile tumours there is much cartilage, mostly on the surface, but some islets may be within the bone. Careful study of these large cartilaginous masses may reveal malignant changes.

The osteochondroma usually ceases to grow and develops a well defined limiting plate of bone at varying periods before or after the age when skeletal growth is ceasing in the affected bone, but the cap of cartilage persists in some cases—to tempt the later development of chondrosarcoma

Treatment. Any osteochondroma causing symptoms should be excised. All larger sessile tumours require excision with a margin of normal bone to protect the patient from some danger of sarcomatous change in this type of osteochondroma. *Indeed*, any large tumour in an adult may well have already undergone such a change, and calls for careful study of the cartilage where active growth is occurring—lest the character of the tumour be underestimated and the surgical treatment be inadequate.

Chondroma

Enchondromata occur commonly in the phalanges and metacarpals, when they are sometimes multiple and more rarely in the long tubular bones, when they are usually solitary

The enchondroma of the hand may cause only a slight expansion of the bone and present with a pathological fracture (20 per cent in Bristol Bone Tumour Register series

of thirty-five tumours in twenty-five patients) In other cases, there is considerable distortion of the contours of the phalanx or metacarpal but a thin layer of subperiosteal bone as a rule still covers the cartilaginous mass. In former times, such a cartilaginous mass occasionally grew to the size of an infant's head, but in spite of the continued growth and the size of the tumour true malignant change with metastases was very rare The sex incidence is about equally divided, and the great majority (72 per cent) appear during the second to the fourth decades. The phalanges and metacarpal bones are equally prone to be involved. These enchondromata of the hand form a distinct group of benign cartilaginous tumours, very rarely undergoing calcification or sarcomatous change. They are readily diagnosed as the *common* cause of a radiolucent area in a phalanx or metacarpal of the hand. The tendency to form further enchondromata sometimes continues until reaching adult life

The chondroma of large bones contrasts in many ways with those of the hand bones. It is rather more than twice as common in men. The age distribution is rather wider only 50 per cent arising during the period 11–40 years, with a considerable proportion occurring during the fourth decade. The site distribution of fifty chondromata of large bones is given in the following Table. (From Geschickter and Copeland, Tables 6 and 7 1949)

Site	*Percentage*
Rib	26
Sternum	14
Femur	12
Humerus	10
Pelvis	8
Vertebra	8
Os Calcis	8
Other bones	14

Malignant changes occur in 25 per cent (sternum, ribs, and long bones) in adults, but not in children (Geschickter and Copeland, page 91) The skiagram shows a central radiolucent area with little or no alteration in the bone outline. When encountered in the long bones, the lesion is usually sited in the metaphysis and has fairly well defined contours (Fig. 187 (*a*)) A mottled appearance indicates calcification, and any irregular cortical perforation may well denote malignant change

Lichtenstein and Hall (1952) have called attention to the rather uncommon periosteal chondroma, first described by Mason (1937). This tumour may appear at any age growing within or beneath the periosteum of a long bone or short tubular bone of hands and feet. It presents as a progressive swelling with pain and local tenderness, and radiography reveals a distinctive picture of an irregular mottled cortical erosion, with dense adjacent sclerosis of the parent bone.

Pathology The macroscopic appearance is usually that of cartilage, but may be softer and more moist from myxoid change, or slightly yellow and gritty from calcification. There are well-defined lobules of cartilage with intervening strands of connective tissue. Microscopically there may be great difficulty in deciding on the benign nature of some of these tumours, which can present a problem as great as any The typically benign cartilage cell has a single small nucleus but an occasional double nucleus can be accepted if small in relation to the cell (Fig. 187 (*b*)). A further distinguishing point of chondroma is that the cartilage is usually small-celled in contrast to that found in osteochondroma

and in many chondrosarcomata and, although the tissue may be very cellular it is uniform and not markedly atypical. Nevertheless, in dealing with a chondroid growth, the site of the lesion, its size, and the clinical and radiographic features are often a better guide to its innocence or otherwise than the histo-morphology (*see* Chondrosarcoma)



FIG. 187( ). CHONDROMA. B.T.R./568 F aged 40. Central Chondroma. This osteolytic lesion presented with pathological fracture and proved to be a chondroma. I the absence of any tell-tale calcification, it is difficult to diagnose in this site, although in the hand a clearly outlined osteolytic area in a slightly expanded bone is typical of enchondroma.

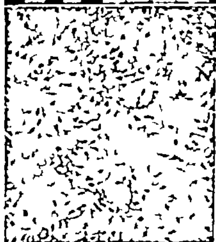


FIG. 187(*b*). CHONDROMA. (H. & E. × 75). B.T.R./321 M aged 29 The cartilage is relatively cellular with considerable variation in size and shape of the chondrocytes. Only an occasional cell however shows double nuclei.

Treatment. While the enchondromata of the small bones of the hand are always adequately treated by careful curettage, sometimes with chemical cauterization, and the use of a bone graft to fill the defect, those of the long bones often call for resection.

Where one is satisfied with the innocent nature of the chondroma, resection with bone replacement would appear to be over treatment, but as there often remains an element of doubt, resection is much to be favoured.

Large chondromata of long bones, pelvis, spine, or thoracic cage should always be regarded as potentially malignant, despite a relatively innocent microscopic structure. Complete surgical removal of such should always be considered and, if possible, carried out.

Benign Chondroblastoma (Jaffe) or Codman's Tumour

Originally described by Codman as a cartilage-containing variant of the giant cell tumour (epiphyseal chondromatous giant cell tumour) and as almost confined to the upper end of the humerus, this tumour has more recently been shown to occur in other sites. Jaffe and Lichtenstein (1942) have contended that this is a special type of cartilaginous growth in which giant cells are incidental. Undoubtedly one of the rarer bone tumours, it occurs largely in males usually in the second decade, thus differing from the giant cell tumour which rarely occurs below 20 years.

Situated in the epiphysis of a long bone, it is usually small in size, rarely bigger than 5–6 cm. in longest diameter although it may extend across the epiphyseal line into the metaphysis or cause local bone expansion (Fig. 188 (*a*)). The radiograph shows a small rarefied area in the epiphysis, well demarcated by a thin line of sclerosis. Slight mottling denoting some calcification in the cartilage greatly assists diagnosis.

Pathology Lichtenstein (p 57) describes the naked eye appearance as grey-brown and firm in consistency sometimes yellowish from calcification The microscopic structure (Fig. 188 (*b*)) reveals masses of compact roundish cells of fair size somewhat resembling fœtal cartilage, with giant cells only in areas of hæmorrhage, or these may be absent altogether Patches of calcification assist in the identification of the tumour Areas of necrosis may be transformed into fibrous, chondroid, or osteoid tissue, occasionally undergoing ossification.

Treatment and Prognosis. Thorough curetting of the lesion, with replacement by bone chips, has proved to be successful. The results were uniformly good in those cases reported by Jaffe and Lichtenstein and in Codman's nine cases, with a follow-up period of 3–10 years. Although this tumour may have an ominous histological appearance Jaffe (1953) has stated that malignant transformation is very unusual.

Osteoid Osteoma

First described in 1935 by Jaffe, it is a lesion occurring sufficiently frequently for most orthopædic surgeons to have encountered one or more cases, and for Jaffe in 1945 to report on sixty-two proven cases. The identity of the lesion is unquestioned but there are many who doubt whether it constitutes a neoplasm.

The nidus of osteoid is very small (up to 1 cm. in length) and occurs in the cortex of a long bone or in the cancellous bone often close to the articular surface. In the latter situation it is sealed off by only a thin layer of reactive bone, but in the former more common situation the reactive sclerotic bone, often extends over a length of the shaft equal to ten to twenty times the size of the nidus, to produce a fusiform thickening of the cortex which is so striking a feature as often completely to obscure the causative focus of osteoid tissue. The tibia and femur are common sites, also the bones of the



FIG. [illegible](*a*) BENIGN CHONDROBLASTOMA. R.N.O.H./12. M. aged 14. This osteolytic lesion involves the epiphysis and has extended here into the metaphysis, resulting in slight expansion of the bone. The lesion is well demarcated by a line of sclerosis. The situation, sex and youth of the patient are suggestive.

(By Courtesy of Professor J. Gough and Mr. E. R. Trowell)



FIG. [illegible](*b*) BENIGN CHONDROBLASTOMA. (H. & E. × 75). R.N.O.H./1. M. aged 14. Typical field showing diffuse arrangement of small polyhedral cells intermingled with occasional giant cells. There is but little inter-cellular matrix to be seen.

foot and the arch of the vertebra the bones of the arm being less often involved Occurring commonly in adolescents and young adults, it is rare over 30 years of age, but may appear in children. Pain is the outstanding clinical feature and it may have persisted for several years with increasing severity *The continued pain may interfere with sleep*

The radiological appearance of the lesion developing close to or within, the cortex is very typical, consisting, as a rule, of a slightly radiolucent area surrounded by a



FIG. 189(*a*). OSTEOID OSTEOMA B.T R./540 M. aged 19 The small radiolucent nidus lies in the centre of an extensive area of thickened sclerotic bone, affecting mainly the cortex in which it is situated.

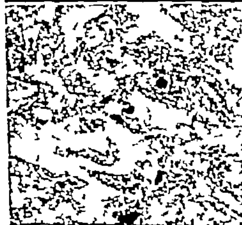


FIG. 189(*b*). OSTEOID OSTEOMA. (H & E. × 80). B.T.R./540. *M. aged 19 Typical field showing* trabeculated arrangement of osteoid—partly calcified, partly ossified. The material is intermingled with vascular fibro-areolar tissue in which both osteoblasts and osteoclasts are prominent.

sclerotic zone extending some distance up and down the bone and thickened both from within and from without (Fig. 189 (*a*)). At times the nidus is only demonstrated in a tomograph. It is occasionally dense from calcification and ossification, and may show in the skiagram as a denser central core in the typically rounded zone of radiolucency The osteoid nidus occurring in cancellous bone is much less obscured by overlying reactive bone. Both may be interpreted as a local abscess with surrounding sclerosis, and the former as Garré's non-suppurative sclerosing osteomyelitis. This lesion, although well recognized, still has strong critics who regard it as being of a reactive nature rather than neoplastic (Brailsford, 1953) It would seem prudent then to be well aware of its existence, but to appreciate that its precise significance remains in doubt.

Pathology Macroscopically the nidus is circumscribed and reddish in colour The histological section (Fig. 189 (*b*)) reveals a core of osteoid often undergoing calcification and surrounded by vascular osteogenic connective tissue and dense circumferential bone.

Treatment. Treatment consists of removing the nidus either in a block of bone or by curetting the lesion either results in immediate relief of pain. In very few reported cases has there been a recurrence of the lesion, but careful and complete curettage is stressed, lest some of the osteoid remain with continuing symptoms.

Non-osteogenic Fibroma

This lesion is usually an incidental finding in a radiograph, which shows an irregular radiolucent zone, eccentrically placed and involving the cortex in the proximal or distal third of a long bone, commonly of the lower limb (Fig. 190 (*a*)). The affected area has a serpiginous outline, clearly delineated by a thin peripheral zone of increased density As a general rule there is no expansion of the bone, which differentiates the lesion from fibrous dysplasia but larger lesions do occur expanding the bone yet showing the typical histology of non-osteogenic fibroma. It is usually found in older children and young adults.

Pathology Macroscopically the tumour may show a yellowish colour due to its content of lipoid-containing "foam" cells

The structure consists of sheets and bundles of whorled fibroblasts in a poorly collagenized matrix (Fig. 190 (*b*)). Osteoid is conspicuous by its absence, but there may be quite a large "foam-cell" component together with a few small giant cells.

Treatment. Many lesions can be safely left. Increase in size is very slow or absent when the lesion is symptomless With a larger lesion, thorough curettage has been effective, and Jaffe and Lichtenstein report no recurrences.

Osteogenic Fibroma (including ivory osteoma)

These tumours are for practical purposes restricted to bones ossified primarily in membrane, i.e. the skull they are but rarely seen elsewhere. In fact, in the very few growths sited in other parts of the skeleton, the histological appearances are, for many indistinguishable from a fibrous dysplasia of bone. Furthermore, some tumours classified under this name are probably ossifying chondromata in which the growth matrix was originally *fibro*-cartilage, or are growths in which, in older persons, endochondral ossification has given place to bone formation in dense fibrous tissue

Many of the lesions present as a painful expansion of the bone which in a radiograph proves to be rarefied, the ossification being a minor feature in such fibromata Other lesions, and characteristically the ivory exostosis of the skull and facial bones, are exceedingly dense, and osteoblastic activity is very prominent (Fig. 191 (*a*)). Hyperostoses over a meningioma, localized Leontiasis Ossea and other inflammatory or reactive hyperostoses must be excluded before accepting the lesion as an ossifying fibroma.

Pathology Microscopically the lesion consists of vascular connective tissue undergoing active osteoblastic metaplasia (Fig. 191 (*b*)) the occasional presence of a number of osteoclasts has led to a mistaken diagnosis of an osteoclastoma. Tumours of the skull often have a characteristic structure the bone being laid down in discrete rounded islets. An osteogenic (or ossifying) fibroma may occasionally attain a very large size and show a polycystic structure.



Fig. 190(*a*). NON-OSTEOGENIC FIBROMA. B.T.R./816. M. aged 13. Situated typically in the distal third of the femur this osteolytic lesion is serpiginous in outline, bounded by layer of dense bone, and involves the cortex of the bone.

Fig. 190(*b*). NON-OSTEOGENIC FIBROMA. (H Ph. & T. × 75). B.T.R./816. M. aged 13. The field shows whorled fibrous tissue and fasciculated spindle cells lying in a fairly collagenous matrix. There is no sign of any osteoid or bone formation.

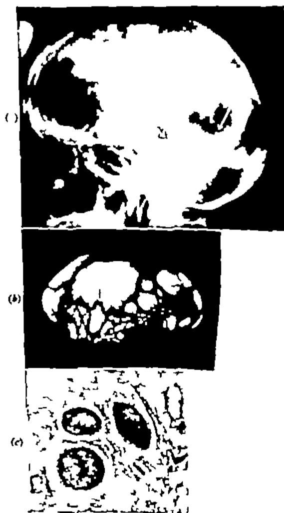


Fig. 191(*a*). OSSIFYING FIBROMA. [illegible] aged 4. This so called "Ivory Exost[illegible] into the posterior fossa of the [illegible] sclerotic and well outlined.

Fig. 191(*b*). OSSIFYING FIBROMA. [illegible] aged 24. The gross appearance [illegible] plaques of bone lying in [illegible]

Fig. 191(*c*). OSSIFYING FIBROMA. B.T.R./341. M. aged 24. There [illegible] matrix of fibrous tissue, in [illegible] new bone are being formed from [illegible] This tumour contains no cartilage [illegible]

Treatment. The tumour may call for surgical removal, and this is often rendered technically very difficult on account of the site and hardness of the lesion.

Chrondromyxoid Fibroma

This rare lesion was first described by Jaffe and Lichtenstein in 1948 and comparatively few cases have been recorded. The interest lies mainly in the fact that it is essentially an innocent lesion, which may be mistaken for a chondrosarcoma and be subjected to unnecessary radical surgery.



FIG. 192(a). CHONDROMYXOID FIBROMA. R.N.O.H./10 F aged 21. The lesion has expanded the bone and appears to be slow growing with extensive moulding of the shaft distal to the tumour. It is sited in the metaphysis, is sharply outlined on its deep surface and shows a trace of pseudo-trabeculation. It proved to be a chondromyxoid fibroma.

(By courtesy of Mr J. I. P. James and Dr H. A. [illegible])



FIG. 192(b). CHONDROMYXOID FIBROMA. (H. & E. × 70). B.T.R./709 M. aged 12. There is an intimate mixture of chondroid, myxoid and fibro-cellular tissue. The ominous cellular appearances sometimes lead to the tumour being misdiagnosed as chondrosarcoma.

The tumour usually arises eccentrically in the metaphysis of a long or tubular bone most often in the lower limb Of the cases reported the majority have appeared in adolescents, but a few have also arisen in later years Both sexes are about equally involved

This slowly growing lesion may give a distinctive radiographic picture (Fig. 192 (*a*)) of an expanded bone with pseudotrabeculation the result of the scalloped surface of the tumour being outlined with a thin layer of sclerotic bone.

Pathology The tumour macroscopically suggests cartilage, but microscopically (Fig. 192 (*b*)) consists essentially of spindle or stellate cells in a mucinous matrix which, however does not give the mucin reaction—hence the term myxoid. Some fields show a chondroid appearance and in mature portions of the tumour collagenization is prominent. In places there may be numerous giant cells and this has led to a mistaken diagnosis of osteoclastoma.

Treatment. Being essentially innocent, these lesions are satisfactorily dealt with by curettage, so far with no published report of local recurrence

Osteoclastoma

This tumour is sometimes called "giant celled tumour" so avoiding any indication of the nature of the multinuclear cell, but most pathologists have accepted the latter as an osteoclast. Willis (1953) states that the giant cell in these tumours is identical with the large osteoclast in bone resorptive lesions, and claims that in both there is much evidence that they are formed as fused aggregates of smaller cells. The smaller oval cells in this tumour are, according to Willis, the bone formative cells, which here possess the attributes of osteoclasts. Accepting the mutability of cell types in bone the bone formative cell is the cell which can change to an osteoblast, osteoclast, chondroblast, or fibroblast as the call arises, accounting for changes which occur in ossification of cartilage, changes in fibrous dysplasia, and the fibrocystic changes and their resolution which occur in hyperparathyroidism before and after treatment. These arguments put forward by Willis and others carry much conviction.

Confusion has arisen over the resemblance between osteoclastoma, myeloid epulis, and the similar if not identical appearances of the "brown tumour" of hyperparathyroidism (Von Recklinghausen tumour)

Willis points out that resemblance does not connote identity and refers one to the similarity between normal cartilage and a chondroma, and between callus and some areas in an osteosarcoma. The main difference lies in the nature of the lesions the osteoclastoma behaves as a progressively growing neoplasm the brown tumour is a local response of tissue to bone resorption, a process which will be reversed by withdrawal of the excessive parathormone while the myeloid epulis is a granuloma, showing all transitions between granulation tissue and osteoclastomatous material.

A confused picture has resulted from inclusion under this heading *Osteoclastoma* of many tumours showing occasional microscopic fields rich in osteoclasts This has led to a sub-group of so-called "giant cell variants." Benign chondroblastoma (Codman's tumour), bone cyst, monostotic fibrous dysplasia, aneurysmal bone cyst, and chondromyxoid fibroma are among the lesions included in this group. Osteoclastoma must be accepted as a definite clinical entity not to be confused with the many conditions

showing occasional osteoclastic fields of activity and the term "giant cell variants" *should be abandoned.*

This tumour accounts for about 5 per cent of all primary skeletal growths and occurs about equally in the sexes, rarely under the age of 20, and most commonly in the third decade. It presents with aching pain or noticeable enlargement of the bone; occasionally a pathological fracture brings the tumour to light. The common sites are the main growing ends of long bones, particularly the lower end of the femur, upper end of the tibia, lower end of the radius, and upper end of the humerus. About half the cases occur in the leg and a quarter in the arm, the remainder in the trunk, in particular the pelvis and vertebræ. When situated in the long bone, an osteoclastoma almost invariably in part occupies that portion of the bone which was formerly epiphysis, thus coming to lie close under the articular cartilage. The tumour usually commences eccentrically, although it may grow to occupy the whole end of the bone. Almost invariably there is expansion of the bone, a subperiosteal thin shell being formed further and further out, and from its brittleness contributing that classical sign of the larger neglected tumour—"egg shell crackling." The aggressiveness of the tumour varies greatly: some grow very slowly and are patently benign, others grow more rapidly, are distinctly aggressive or malicious, while still others are malignant and will be discussed later.

Radiographic Appearance. The eccentric expansion of the end of a long bone by an osteolytic lesion, coming close up to the articular surface as a rule, and rather sharply limited at the diaphyseal extremity (Fig. 193 (*a*)), frequently presents a sufficiently characteristic lesion to lead some to conclude that the diagnosis could safely be made on the radiograph (Brailsford, J. F., 1953). This, however, is far from the truth. Coarse trabeculæ occasionally cross the lesion in the more slowly growing tumours, while in the more aggressive, the cortex may be perforated, and the diaphyseal limit of the tumour be very indefinite without it being malignant. *No radiograph can be accepted as diagnostic,* as other conditions may present a very similar picture and a biopsy is always required.

Pathology. The tumour in the gross appearance consists of soft dark-red friable tissue occupying the expanded end of a long bone or a portion, if not the whole, of a small bone.

Microscopically the tumour consists of spindle or oval cells, amongst which are found the large multinuclear cells, the osteoclasts (Fig. 193 (*b*)). These large cells vary in size and may contain twenty to forty nuclei, which tend to collect towards the centre of the cell. Large areas of necrosis and hæmorrhage are common, and around the latter amongst the proliferating survivor cells, mitoses may usually be found. The variation in the behaviour of osteoclastomata, and in particular the occasional malignant type (15 per cent Lichtenstein, page 107 *et seq.*), has called for some method of grading, and this has been performed by Jaffe, Lichtenstein, and Portis (1940), on the basis of morphological variations in the stromal cells, and the osteoclasts. Many pathologists have used this grading and have found a close correspondence between the grade given to the tumour and its subsequent behaviour (Thomson, 1956). (*See* Malignant Osteoclastoma.)

Complications. An osteoclastoma may present with a fracture, or sustain one at a later date. In either case this complication is serious since the articular surface is inevitably involved and the function of the joint often markedly impaired. Any large series of

osteoclastomata will show instances of local recurrence of the tumour no matter what line of treatment is followed, and it is probable that Grade II tumours comprise most of the recurrences. Grade III tumours may metastasize producing secondaries in the lungs histologically identical with the parent growth. Grade III tumours occasionally



FIG. 193(*a*). OSTEOCLASTOMA. B.T.R./190 M. aged 61 This osteolytic lesion is eccentric, has caused expansion of the bone and is situated, quite typically in the end of an adult long bone, limited in places by only a thin osseous layer beneath the articular cartilage.



FIG. 193(*b*). OSTEOCLASTOMA. (H.Ph. & T × 160) B.T.R./868 M. aged 32. Typical field of an osteoclastoma, the structure of which conforms with that of a Grade II tumour Mitoses are but infrequently seen in the stromal cells, but may usually be found around the edge of an area of hæmorrhage.

break down after surgery with the introduction of sepsis, thus leading to the unjustified claim that this had caused a malignant transformation. A Grade III tumour also frequently recurs after treatment, so that this type of tumour is often treated by radiotherapy and surgery encouraging a further erroneous claim that cases treated by a combination of treatments often become frankly malignant. However there is occasionally

a change of this tumour to a more malignant type and a recurrence sometimes shows this mutation, no matter what treatment has been applied. One must also refer to the complication which arises when the innocent lesion, rendered sclerotic by radiotherapy blazes forth into a sarcoma some 10–20 years later Here there is a long latent period, and the malignant tumour is most often a fibrosarcoma.

The literature on this tumour contains well-documented cases of osteoclastoma which have been malignant ab initio other cases which have metastasized to the lungs, although apparently of low grade, and other cases again in which malignancy has appeared as a late complication following upon supposedly successful treatment. The overall incidence of malignant forms of this growth are variously given, and run from 3·7 per cent (Simmons, 1931) to 19 per cent (Meyerding and Jackson, 1950), intermediate figures of 13 per cent (Windeyer and Woodyate 1949), and 15 per cent (Coley 1935), indicating that about 15 per cent would be the probable figure

Treatment. Treatment of any case of osteoclastoma must be prefaced by a biopsy and sections of the tissue should, if possible, be graded by an experienced histologist. The clinical and radiological pictures are quite inadequate for a firm diagnosis. Where the gross appearances at operation support the tentative diagnosis, it is permissible to proceed to a careful and thorough *curettage* of the whole lesion Adequate unroofing is demanded and blind areas, e.g. the cortex close to the articular cartilage must be reduced to a minimum. The operation is performed with hæmostasis provided by a tourniquet and the curettage must be thorough, the destruction of tumour cells being rendered almost complete when one proceeds finally to apply a wool pledget soaked in saturated Zinc Chloride solution to the walls of the cavity This strong caustic must be used abstemiously and only applied within the bone, which is finally liberally washed out with saline Chip grafts may be introduced to fill the cavity should it be large. This procedure is sufficient treatment for a Grade I tumour and for many Grade II osteoclastomata. It is associated with minimal disability and has virtually no danger of provoking malignant changes.

Some tumours are suitably placed for *resection*—a procedure much to be preferred where it can be practised without affecting function The upper end of the fibula and lower end of the ulna are examples of this, where the tumour can be removed intact and enclosed within its periosteum. Such cases are best treated without prior biopsy since the whole specimen will provide the histological material

In cases where the function of the joint is already impaired, resection of the upper end of tibia or lower end of femur with bone graft and arthrodesis of the knee, or a similar *resection arthrodesis* of the wrist, may sometimes be the best treatment.

An osteoclastoma of Grade III should probably be treated by *amputation*, as it is only too easy with an osteoclastoma to leave ablation until too late Stripped of all its so called *tarlatis* the osteoclastoma is a formidable tumour and can be frankly malignant. There is no justification for ever using the deceptive benign" as a prefix to the term giant cell tumour or osteoclastoma, unless so proven by exhaustive histological examination and extended subsequent history

Turning from the treatment of osteoclastoma by surgery alone, we must consider whether there is any place for *combined treatment by surgery and irradiation* Fatal malignant cases are frequently found to have received treatment by surgery and subsequently by irradiation, or the reverse but this must not be taken as necessarily

implying any specific danger of combined treatment, as recourse to both lines of treatment almost certainly has resulted from the malignant persistence of the tumour

A number of cases in most series, however show planned treatment by surgery and irradiation, and it would seem doubtful whether there is any advantage or sound rationale in thus confusing the issue. This practice no doubt results from the invariable need for a biopsy of the tumour and surgery is only pursued to what is deemed an incomplete removal of tumour tissue.

Radiotherapy has an important contribution in treating the more inaccessible tumours, of which the vertebræ, and in particular the sacrum, traversed by important sacral nerve roots, are the best examples. The more accessible tumours when treated by irradiation, run as great a risk of recurrence and of disturbance of joint function by subsequent fracture as do such cases treated by surgery The lesions become sclerosed, and expansion ceases, but latent neoplasm has been identified in biopsy of such cases

The repeated irradiation of osteoclastoma, which was the practice some years ago has contributed to an ever growing literature of sarcoma of bone developing several years later (Cade, 1949). There is no comparison between modern irradiation treatment and the above, but some anxiety on this account must linger in our minds.

The literature contains many series of osteoclastomata unproven by biopsy and often containing a ballast of much less aggressive lesions. There is still a need for completely documented reports of series of cases, carefully controlled by biopsy and grading, treated by a single line of treatment, whether surgery or radiotherapy and with a generous follow-up period—a 10 year minimum.

Where recurrence occurs after surgical treatment or radiotherapy a very difficult decision faces the clinician. Radiotherapy may succeed where surgery has failed a wide surgical ablation may result in a cure but, in some, amputation will be called for before it is too late A further biopsy and regrading of the tumour will be a great help in arriving at a most difficult decision.

Hæmangioma

This is a rare tumour of bone affecting the skull most commonly two-thirds of all lesions occurring in the skull or vertebræ (Sherman, 1944) The anatomical studies of Töpfer (1928) are repeatedly quoted as showing hæmagiomata in approximately 12 per cent of the spines of 2,000 subjects examined at autopsy but Lichtenstein (page 120) points out that none of these lesions appear to have provoked any clinical symptoms, nor had they been recognized radiographically He suggests that these lesions may well be more analogous to varices within the bone than true hæmangiomata, which he still maintains are rare tumours.

The not infrequent site of an aneurysmal bone cyst in the posterior arch of a vertebra makes it possible that some of these have been diagnosed as hæmagiomata, although many pathologists take the view that aneurysmal bone cyst is merely a form of angioma modified by its inclusion in bone Symptoms of a hæmangioma vary with the site the slow growth will make symptoms arising from the bone of a very minor nature, but there may be pressure on the brain, spinal cord, or nerve roots in those tumours occurring in skull or vertebræ.

In a radiograph (Fig. 194 (*a*)) a hæmangioma of skull is likely to present as an area of rarefaction, honeycombed and tending to bulge the outer cortex. A frequent feature of

great diagnostic help is the so called "sun ray" appearance with spicules of reactive bone radiating from the centre of the lesion

In the vertebral body the lesion is characterized radiologically by accentuation of the vertical trabeculæ, the transverse trabeculæ being less conspicuous than usual. The vertebral body is usually of diminished density and in some instances the whole bone is involved by the angioma. Lesions elsewhere also often show parallel spicules of reactive



FIG. 194(*a*) HÆMANGIOMA. B.T.R./88 F aged 46 This shows an osteolytic lesion of the skull, expanding the bone and precise in outline. The almost parallel trabeculæ of reactive bone radiate from the centre of the lesion to give the so-called sun ray appearance

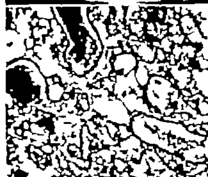


FIG. 194(*b*) HÆMANGIOMA. (H & E. × 35). B.T.R./152. *M aged 35 This is a cavernous angioma*, the structure of which resembles that of vascular tumours of the soft tissues. A considerable amount of reactive new bone formation may sometimes be seen.

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Adamantinoma

This tumour develops insidiously often over a period of some years, gradually extending but showing no tendency to metastasize, even after unsuccessful attempts at local excision. The tumours are fairly common in the jaws during early adult life, but have occasionally been reported in children and the aged The mandible is involved about six times as often as the maxilla by this growth which should be regarded as benign, but potentially malignant. The sexes are about equally divided in any large series of cases.

Apart from adamantinoma occurring in the jaws and readily explained by association with the teeth, similar tumours are rarely encountered in the tibia, and have also once been reported in the ulna and once in the femur

Radiographically this tumour most often presents as a mono- or polycystic or even honey combed area of bone destruction in the posterior part of the horizontal ramus of the mandible, sometimes with extension into the ascending ramus. The radiolucent area has well defined cortical margins and may show coarse bony trabeculæ running across. There may be slight bone expansion, but the cortex is usually intact. The lesion is slowly progressive.

In the tibia (Fig. 195 (*a*)) it presents as a localized, cystic area, slightly expanding the bone but with an intact overlying cortex and sclerotic limiting wall

The histological picture (Fig. 195 (*b*)) shows an alveolar or trabeculated pattern of palisaded cubical or low columnar epithelium embedded in a fibro-areolar stroma. The epithelial alveoli may show centrally the delicate and characteristic "stellate reticulum," often merging into areas of



(*a*)

(*b*)

FIG. 195(*a*) ADAMANTINOMA. R.N.O.H./38. M aged 43 This tumour affects the tibia almost exclusively among the limb bones, causing slight expansion by an osteolytic lesion bounded everywhere by a zone of sclerotic bone The tumour illustrated here is more extensive than usual.

(By courtesy of Dr W. R. Davis)

FIG. 195(*b*). ADAMANTINOMA. (H & E. × 70). R.N.O.H./38. M aged 43 The field shows islets of compressed epithelial cells embedded in dense fibro-areolar stroma. Occasionally there is some suggestion of "palisading" of the basal layer of cells, or frank metaplasia with contingent keratinization.

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bone within a *well demarcated expanded* lesion of a bone with a long history of mild complaints, so that on clinical and radiological grounds, a tentative diagnosis of hæmangioma can be made.

The histological picture (Fig. 194 (*b*)) is one of a capillary or cavernous hæmangioma, as seen in other tissues, but showing bony trabeculæ, either reactive or preserved from the original structure

Treatment. Some lesions can be excised, but according to Watson and McCarthy (1940) radiotherapy is the treatment of choice for vertebral lesions, giving complete relief of symptoms without resort to a rather dangerous and difficult operation.

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squamous metaplasia or cystic structures. Metastasis to local lymph nodes and lungs has been reported.

Much speculation has naturally been aroused by the fact that the lesion arises almost exclusively in limb bones with subcutaneous surfaces or borders. A very plausible explanation put forward is that these rare tumours arise from cell rests derived from the skin the overlying intact cortex makes it unlikely that such rests could result from trauma, and in all probability they should be explained as a developmental anomaly

Treatment. The frequency of recurrence demands a very thorough removal of the tumour with all affected bone by block excision a very large or recurrent lesion in a limb will call for amputation. Radiotherapy has been used in treating adamantinoma, but the results have been unsatisfactory and eventual resort to surgery has been required.

Subperiosteal Lipoma

This rare situation for a lipoma is mentioned for completeness, although few surgeons have experience of a case. As with lipomata in their more common sites, they are very slow growing and painless and usually discovered accidentally as a painless swelling, in this case applied so firmly to the bone as to suggest a soft tumour arising from the bone *A radiograph taken by soft tissue technique will show the tumour* there may be some absorption of the underlying bone, giving a shallow excavation, but otherwise the structure of the bone is not distorted.

Treatment, when called for is by local excision.

MALIGNANT PRIMARY TUMOURS OF BONE

Osteogenic Sarcoma

An osteogenic sarcoma is not necessarily a bone forming sarcoma, but a sarcoma *derived from the connective tissues in bone* The osteogenic series of sarcomata comprise those malignant tumours derived from the osteoblasts, chondroblasts, or fibroblasts or their precursors in bone. These three cells are according to Willis, merely different phases of the "bone formative cell." The mutability of these three variants of the connective tissue cell now has a sound experimental basis, hence one may readily understand the marked heterogeneity of cell structure encountered in primary bone sarcoma. Osteogenic sarcoma excludes the osteoclastoma, which when malignant may retain its characteristic appearance, although it often becomes anaplastic and indistinguishable from an osteogenic sarcoma.

The osteogenic series are characterized by well marked cell pleomorphism in the majority by a diverse and rich matrix which may be collagenous fibres, chondroid, osteoid, or bone, or mixtures of any of these four In a typical example mitoses are numerous (up to 2 per cent of all cell nuclei), and Price (1951 1956) has shown that the proportion of mitoses to resting cell nuclei may be used as an index for tumour grading.

In any large series the growths may conveniently be divided into three sub-groups with practical benefit

(1) Osteosarcoma (osteoblast sarcoma)

(2) Chondrosarcoma.

(3) Fibrosarcoma.

In this we agree with the classification recently published by Thomson and Turner Warwick (1955). We may then use these three names to connote three closely related

varieties of osteogenic sarcoma which are characteristically osteoid/bone, cartilage, or fibre forming.

The osteosarcoma presumably derived from the more primitive mesenchymal cell in its higher grades (II+) usually shows much cell pleomorphism, although tumours of Grade I may be well nigh as orderly as a benign osteochondroma. Nevertheless, even in the most atypical and cellular specimens, it is usual somewhere to find evidence of tumour osteoid chondrosteoid, or bone which must, however be distinguished from purely reactive tissues. The tumour may show a considerable amount of cartilage and form much bone through this intermediary yet in some fields the *essential property of forming osteoid or bone directly from the tumour cell will be seen.*

The chondrosarcoma was originally set apart by Phemister in 1930 on clinical, prognostic, as well as on pathological grounds it presumably originates from cartilage found centrally or peripherally in the bone, producing a tumour either largely confined within the bone or extending freely on the surface. The essential features of this tumour are that it consists mainly of nodular masses of atypical cellular cartilage showing both interstitial and appositional growth. Also even in the more cellular areas, cells may still be recognized as modified chondrocytes or chondroblasts Definite osteoid matrix is relatively infrequent, and bone formation is a secondary phenomenon overshadowed by stromal degeneration and calcification. Specimens, however are encountered in which it seems futile to attempt to decide whether the tumour must be designated osteosarcoma or chondrosarcoma.

Fibrosarcoma has more recently been recognized as a separate entity within this osteogenic series thus is often a central sarcoma with fibroblasts and interlacing collagenous fibres. Thomson and Turner Warwick (1955) have further separated a small group of "spindle cell sarcomata," indicating their uniform histo-morphology their relative lack of mitoses and their failure to develop any recognizable matrix. In spite of their lack of differentiation, the outlook is not hopeless. Further study alone will decide the propriety of this segregation.

In 1943 an excellent analysis by Macdonald and Budd of the 5 year "cures collected by the American Registry of Bone Sarcoma revealed a very important prognostic significance in the osteogenic sarcomata as to whether they were fibrosarcomata or osteosarcomata, the chondrosarcoma occupying an intermediate position. They showed that among the "cures" the fibrosarcomata accounted for 31 per cent, the chondrosarcomata 46 per cent, and the *osteosarcomata 12 per cent, the remaining 11* per cent comprising four cases which they considered sufficiently well differentiated towards more than one type of tissue to deserve a compound name, and six cases discarded as not osteogenic sarcomata Among a smaller unselected series of fatal cases, fibrosarcomata accounted for only 15 per cent, the remaining 85 per cent being about equally distributed between osteosarcomata and chondrosarcomata. Although the chondrosarcomata accounted for the greatest number of cures, they occur in about equal percentage in cured and uncured series, sharing with osteosarcoma 85 per cent of the fatal cases. The large number of chondrosarcomata in this series suggests that "chondroblastic osteogenic sarcomata"* are being included under this term. As these chondroblastic

* The term "chondroblastic osteogenic sarcoma" has, of recent years, been used by the authors and in the literature for a variant of osteosarcoma, which although osteoid-forming yet contains much tumour cartilage. This growth was formerly designated "Primary Chondrosarcoma" by some writers, e.g. Geschickter and Copeland (1949).

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The osteosarcoma, presumably derived from the more primitive mesenchymal cell, in its higher grades (II+) usually shows much cell pleomorphism, although tumours of Grade I may be well nigh as orderly as a benign osteochondroma. Nevertheless, even in the most atypical and cellular specimens, it is usual somewhere to find evidence of tumour osteoid, chondrosteoid, or bone which must, however be distinguished from purely reactive tissues The tumour may show a considerable amount of cartilage and form much bone through this intermediary yet in some fields the *essential property of forming osteoid or bone directly from the tumour cell will be seen*

The chondrosarcoma was originally set apart by Phemister in 1930 on clinical, prognostic, as well as on pathological grounds it presumably originates from cartilage found centrally or peripherally in the bone, producing a tumour either largely confined within the bone or extending freely on the surface The essential features of this tumour are that it consists mainly of nodular masses of atypical cellular cartilage showing both interstitial and appositional growth. Also even in the more cellular areas, cells may still be recognized as modified chondrocytes or chondroblasts. Definite osteoid matrix is relatively infrequent, and bone formation is a secondary phenomenon overshadowed by stromal degeneration and calcification. Specimens, however are encountered in which it seems futile to attempt to decide whether the tumour must be designated osteosarcoma or chondrosarcoma.

Fibrosarcoma has more recently been recognized as a separate entity within this osteogenic series this is often a central sarcoma with fibroblasts and interlacing collagenous fibres. Thomson and Turner Warwick (1955) have further separated a small group of "spindle cell sarcomata," indicating their uniform histo-morphology their relative lack of mitoses and their failure to develop any recognizable matrix. In spite of their lack of differentiation, the outlook is not hopeless. Further study alone will decide the propriety of this segregation.

In 1943 an excellent analysis by Macdonald and Budd of the 5 year "cures" collected by the American Registry of Bone Sarcoma revealed a very important prognostic significance in the osteogenic sarcomata as to whether they were fibrosarcomata or osteosarcomata, the chondrosarcoma occupying an intermediate position. They showed that among the "cures" the fibrosarcomata accounted for 31 per cent, the chondrosarcomata 46 per cent, and the osteosarcomata 12 per cent, the remaining 11 per cent comprising four cases which they considered sufficiently well differentiated towards more than one type of tissue to deserve a compound name and six cases discarded as not osteogenic sarcomata. Among a smaller unselected series of fatal cases, fibrosarcomata accounted for only 15 per cent, the remaining 85 per cent being about equally distributed between osteosarcomata and chondrosarcomata. Although the chondrosarcomata accounted for the greatest number of cures, they occur in about equal percentage in cured and uncured series, sharing with osteosarcoma 85 per cent of the fatal cases. The large number of chondrosarcomata in this series suggests that "chondroblastic osteogenic sarcomata"* are being included under this term. As these chondroblastic

* The term "chondroblastic osteogenic sarcoma" has, of recent years, been used by the authors and in the literature for a variant of osteosarcoma, which although osteoid-forming yet contains much tumour cartilage. This growth was formerly designated "Primary Chondrosarcoma" by some writers, e.g., Geschickter and Copeland (1949).

squamous metaplasia or cystic structures. Metastasis to local lymph nodes and l
has been reported.

Much speculation has naturally been aroused by the fact that the lesion arises al
exclusively in limb bones with subcutaneous surfaces or borders. A very plat
explanation put forward is that these rare tumours arise from cell rests derived fror
skin the overlying intact cortex makes it unlikely that such rests could result
trauma, and in all probability they should be explained as a developmental anoma

Treatment. The frequency of recurrence demands a very thorough removal o
tumour with all affected bone by block excision a very large or recurrent lesion
limb will call for amputation. Radiotherapy has been used in treating adamantin
but the results have been unsatisfactory and eventual resort to surgery has been requ

Subperiosteal Lipoma

This rare situation for a lipoma is mentioned for completeness, although few surg
have experience of a case As with lipomata in their more common sites, they are
slow growing and painless and usually discovered accidentally as a painless swellin
this case applied so firmly to the bone as to suggest a soft tumour arising from
bone *A radiograph taken by soft tissue technique will show the tumour* there ma
some absorption of the underlying bone, giving a shallow excavation, but otherwise
structure of the bone is not distorted.

Treatment, when called for is by local excision

MALIGNANT PRIMARY TUMOURS OF BONE

Osteogenic Sarcoma

An osteogenic sarcoma is not necessarily a bone forming sarcoma, but a sarc
derived from the connective tissues in bone The osteogenic series of sarcomata comp
those malignant tumours derived from the osteoblasts, chondroblasts, or fibroblast
their precursors in bone. These three cells are, according to Willis, merely diffe
phases of the "bone formative cell." The mutability of these three variants of
connective tissue cell now has a sound experimental basis, hence one may readily un
stand the marked heterogeneity of cell structure encountered in primary bone sarco
Osteogenic sarcoma excludes the osteoclastoma, which when malignant may retai
characteristic appearance, although it often becomes anaplastic and indistinguish
from an osteogenic sarcoma.

The osteogenic series are characterized by well marked cell pleomorphism in
majority by a diverse and rich matrix which may be collagenous fibres, chondr
osteoid, or bone, or mixtures of any of these four In a typical example mitoses
numerous (up to 2 per cent of all cell nuclei), and Price (1951 1956) has shown that
proportion of mitoses to resting cell nuclei may be used as an index for tumour grad

In any large series the growths may conveniently be divided into three sub-gro
with practical benefit

(1) Osteosarcoma (osteoblast sarcoma).

(2) *Chondrosarcoma.*

(3) Fibrosarcoma.

In this we agree with the classification recently published by Thomson and Tun
Warwick (1955). We may then use these three names to connote three closely rel

varieties of osteogenic sarcoma which are characteristically osteoid/bone cartilage or fibre forming.

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osteogenic sarcomata are of a malignancy equal to osteosarcoma, to which they really belong in spite of the plentiful supply of cartilage in the tumour this classification has rendered the malignancy of chondrosarcoma unduly high and the frequency of this lesion excessive. Chondrosarcoma and fibrosarcoma have a better prognosis than osteosarcoma, as shown by both Macdonald and Budd and Thompson and Turner Warwick in reviewing large series. The very important point brought out by the former authors is that "while early treatment must save certain patients, it may be assumed that curability depends more on the natural selection than on any other single factor" It has also been shown by Price (1952, 1956) that the 5-year cure rate, at least in osteosarcoma, closely approximates to the incidence of low grade tumours (Grade I). Macdonald and Budd also reported that biopsy was as frequently performed among the "cures" as among the fatal cases but the series are definitely *not comparable*

The rare parosteal fibrosarcoma does not belong to the osteogenic sarcoma group and is aptly described by these authors as "that spurious pretender to osteogenic status." It is extra-osseous and has a prognosis in line with fibrosarcoma of the soft tissue.

Osteosarcoma or Osteoblast Sarcoma

This tumour is almost the commonest primary malignant tumour of bone. It occurs more frequently in males (60 per cent) and between the ages of 10 and 25 years, from then onwards becoming progressively less common until the second peak occurs with osteosarcoma arising in Paget's disease, usually over the age of 50 years A recent analysis of one hundred and forty osteogenic sarcomata (osteosarcoma and fibrosarcoma variants) has indicated that the tumour incidence is probably even higher amongst persons over 50 years than it is amongst adolescents and young adults (Price, 1955). Osteosarcoma is rare in very young children

Factors Affecting the Development of Osteosarcoma. Besides the factor of bone growth, which appears to influence the site and accounts for the large number of cases occurring in the second decade, there is also a definite relationship between osteitis deformans (and exceptionally other degenerative lesions, e.g. monostotic fibrous dysplasia), ionizing radiation, and the development of osteosarcoma.

Osteitis Deformans or Paget's Disease. Paget himself was the first to draw attention to the risk of osteosarcoma developing in any case of osteitis deformans, which occurred in five of his eight original patients The frequency with which osteitis deformans occurs without causing any symptoms makes it impossible to assess the amount of osteitis deformans in any community Pathological fracture is a not infrequent complication and to this an undisclosed sarcoma is very occasionally a contributory factor revealing itself by progressive bone destruction and a growing tumour mass. Any estimation of the risk of malignant change is very inaccurate but it is usually considered to be between 5 per cent and 10 per cent. Price (1955) has reported that in patients over the age of 50 years with osteogenic sarcoma, at least one half will show well advanced Paget's disease of about equal sex incidence Malignant change usually reveals itself as osteosarcoma, but fibrosarcoma, chondrosarcoma, and even malignant osteoclastoma, have been reported. The age of onset is usually over fifty years multifocal cases are not infrequent, and a rapidly fatal outcome is almost invariable

Ionizing Radiations. In bone, prolonged irradiation, however applied, has a considerable tendency to provoke sarcomatous change.

Martland, in 1931 reported cases of osteogenic sarcoma which developed in America in young women exposed to the risk of ingesting radio-active paint. There were five patients who died from osteogenic sarcoma in three of the five cases the tumour was multifocal. This group forms a classical example of the malignant transformation occurring in bones under prolonged irritation by radioactivity Instances are also reported following radiotherapy to bones, and there is a considerable volume of work on osteogenic sarcoma in animals experimentally induced by ionizing radiations, usually administered in the form of radioactive compounds which will localize preferentially in bone and mineralized tissues. A section on irradiation sarcoma is to be found at the end of this chapter

Trauma. While there is a popular opinion that trauma can play a part in initiating osteosarcoma, it would seem that trauma is so ubiquitous among the young that little can fairly be drawn from the clinical histories other than that trauma may have played a part in drawing attention to the lesion in a few cases. One is inclined to agree with Willis, who sums up by saying "the only attitude for a scientific pathologist is one of stringent scepticism." *Pathologist* can fairly be replaced by *Surgeon* without making the adjective appear out of place!

Clinical Picture. The skeletal sites most frequently affected are those in which "the growth period is longest and growth momentum is greatest" (Christensen, 1925) Hence 50 per cent of all tumours are near the knee joints in the metaphyseal region of the lower end of femur and upper end of tibia. Any bone may be affected but the long bones most commonly and the leg in 65 per cent of all cases. In later years (over 50) one meets relatively more growths of the flat bones (pelvis, scapula) and, although the femur is still by far the bone most frequently involved, an increasing number of tumours arise in the diaphysis and upper end. This may be attributed to the manner in which Paget's *disease* affects the skeleton However although Paget's disease of the skull and spine are common both these sites are but rarely involved by sarcoma.

In spite of the serious prognosis, the patients usually appear in good health, unless the pain is already causing much loss of sleep This appearance of good health results from the fact that the pain usually makes the patient present himself before the doctor within a few weeks. The pain varies with the rate of growth but is almost always of a continuous nature. There is usually some palpable thickening of the bone, often a considerable tumour Rarely there is some warmth from hyperaemia, or visible dilatation of veins.

The radiograph (Fig. 196 (a)) usually shows most, if not all, of Codman's five radiographic signs

(1) The tumour is creative and destructive, although one or other factor may dominate the picture.

(2) The tumour affects both cortex and medulla.

(3) The outline of the normal shaft can be followed through the lesion no gross remodelling has occurred unless due to pre-existing osteitis deformans.

(4) Codman's triangle of *reactive* bone. This is new bone laid down by the elevated periosteum distal or proximal to the tumour and brought to an abrupt cessation by the destructive action of the neoplasm, leaving a triangle of bone elevated from the bony cortex at the limit of the lesion.

(5) The soft tissue shadow rising from the bone.

Some cases feature as osteoblastic lesions, others as osteolytic, but all tend to show most of these features which make up the radiological characteristics of an osteosarcoma. One should also regard as probably sarcomatous any lesion which radiographically appears as a solitary ill-defined area of increased osseous density in the metaphysis of a juvenile long bone. The skiagrams at an early stage may show no other abnormality



FIG. 196(a). OSTEOSARCOMA. B.T.R./754. F aged 15. Osteosarcoma of humerus, metaphyseal in situation and showing osteoblastic and osteolytic areas involving cortex and medulla. The clear outlines of the original shaft without any adaptive moulding indicate the rapidity of growth. The reactive bone is seen in spicule formation and in Codman's triangles, and the soft tissue shadow is well illustrated in this radiograph.

FIG. 196(b). OSTEOSARCOMA (H. & E. × 160). B.T.R./754. F aged 15. The tumour is seen to consist of irregular masses of osteoid, separated by angular and polyhedral cells which, in this instance, are relatively uniform. There are also a few small tumour giant cells present.

save this. The sun ray appearance from reactive subperiosteal bone laid down by the periosteum, which is being progressively pushed outwards, is often considered to be characteristic; it is, however, not infrequently absent and can be seen in secondaries from neuroblastoma, secondary carcinoma, and even in hyperplastic callus.

Although many cases give a characteristic radiological picture, others are recognized with difficulty All must be confirmed by biopsy before embarking upon treatment

Pathology The blood alkaline phosphatase is frequently found to be raised in these cases, to fall after amputation and rise again in the presence of metastases or recurrence. One must however bear in mind also that the blood alkaline phosphatase is often raised in Paget s disease—in the absence of any sarcoma.

The sarcoma usually grows from the bone on all surfaces, the greyish white soft tissue lesion being considerably larger than the ossified portion seen on the radiograph. Besides the outward extension, there is a medullary plug extending away from the epiphysis occasionally there is a separated portion in the medullary cavity this might be left behind in the amputation stump and this medullary extension calls for care in selecting the level for amputation. Moreover the tumour spread in both cancellous and compact bone is usually much more extensive than may be judged from examination of clinical radiographs

Glandular involvement is very rare, although cases have been recorded. Metastases usually develop in the lung and may ossify Metastases have been reported in skin, other bones, and liver and brain.

Histology Histologically the picture (Fig. 196 (*b*)) varies greatly from case to case, some showing much new bone formation, others merely a trace, but the essential characteristics are a more or less pleomorphic cellular tissue, mainly spheroidal or spindle celled, showing mitoses to an extent varying with the malignancy (Price, 1952) and the formation of bone or osteoid in the intercellular spaces. Much cartilage may be present with calcification and ossification of this tissue, but the tumour should be desig nated osteosarcoma if the sarcoma shows the property in places of forming osteoid or bone directly from the tumour cells.

Prognosis. This has largely been dealt with in previous paragraphs One should add, however that the prognosis is particularly bad in the very young and the elderly and the peripheral tumours carry a lower mortality rate than those in the trunk and upper end of femur and humerus. Macroscopic encapsulation appears to be of great importance in prognosis (Macdonald and Budd, 1943)

Treatment. Treatment is by surgery or irradiation, the mortality remaining high in either case Unfortunately so many patients have seedling sarcomata in the lungs at the time of diagnosis, even when this is made early that their fate is sealed no matter what the treatment. A large number of patients die within the year from these metastases in the lungs, and 80 per cent of all within 2 years. A natural selection is, therefore, in operation, so that delay in amputation raises the cure rate of those amputated, as shown by Ferguson (1940) in reviewing cases of osteogenic sarcoma in the American Bone Sarcoma Registry His conclusions that a more propitious phase was reached by a delay in treatment for 6 months is not accepted, as the results he showed can be better explained by natural selection. Macdonald and Budd (1943) amplified this point and demonstrated that those patients with osteogenic sarcoma in the American Bone Tumour Registry surviving 5 years showed a fibrosarcoma morphology of 31 per cent. If treatment is to be by surgery it must surely be called for without delay lest the patient develops metastases in the interval. Surgery must also be radical, but while amputation proximal to the affected bone is usually called for the conservative amputation through the femur in the many cases of osteosarcoma of the lower end has not led to any worse results nor

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FIG. 196(*a*). OSTEOSARCOMA. B.T.R./734. F aged 15 Osteosarcoma of humerus, metaphyseal in situation and showing osteoblastic and osteolytic areas involving cortex and medulla. The clear outlines of the original shaft without any adaptive moulding indicate the rapidity of growth. The reactive bone is seen in spicule *formation and in Codman's triangles, and the* soft tissue shadow is well illustrated in this radiograph.



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increase in the rare local recurrence. A useful stump is thus preserved, but care must be taken to amputate proximal to any medullary extension, the bone section being at a minimum of 4 in. from the radiological and clinical proximal limit of the tumour mass. Local resection has little place in the treatment of osteosarcoma, but it may have to suffice in tumours of the bones of the trunk, and may deserve consideration where the tumour is undoubtedly Grade I (mitoses less than 0.2 per cent of all tumour cell nuclei) of small size, and is contained within the limits of the periosteum.

The role of radiotherapy in the treatment of osteogenic sarcoma has grown with the increased power of the radiotherapists weapons the 2-4 million volt X-ray apparatus and the 2-10 gm. teleradium units can, undoubtedly produce cases of survival from 5-30 years, fairly described as cures. Similar useful results may also be expected from the large radio-cobalt unit. Cade (1955) has recently reported upon a large series of patients, some subjected to amputation at a later date, but others treated entirely by radiotherapy Although a small number were described as primarily radio-resistant, the remainder responded to 7,000-9 000 röntgen units in courses extending over 8-12 weeks and showed clinical radiological, and pathological changes of great interest. The tumours shrank, pain was relieved, and although joints lost some movement, the function often remained good. Leathering of tissues did occur but was attributed to faults in technique, and was not thought of any importance where later amputation was planned, as in the earlier cases. The radiographs showed cessation of extension of the tumour increased density and well defined limits to the bony mass. Biopsies reveal few mitoses, some degenerate cells and nuclei, fibrosis and later ossification. Whole fields may reveal no trace of tumour cells. Cade appears to have substantiated the effectiveness of radiotherapy in this tumour formerly classified among the relatively radio-resistant.

It would be interesting to know the percentage of osteosarcomata, chondrosarcomata, and fibrosarcomata in this series, which include all three groups of osteogenic sarcomata, and to know whether the analysis was in conformity with that of Macdonald and Budd (1943)

The Choice of Treatment. While many patients are doomed by the presence of invisible tumour seedlings in the lungs at the time of diagnosis, those that have not would be well advised to part with their tumour and a portion of the limb. Do these fortunates account for no more than 10-15 per cent, a survival rate reported in certain amputation series? Many suffer amputation but still die of secondaries but can radiotherapy dispel the gloom caused by invisible lung seedlings already present at the time of diagnosis? The removal of the tumour gives relief from pain and a modicum of hope. There is a tremendous difference between amputation of the leg, with the excellent function of the modern artificial limb, and amputation of the arm, with the permanent loss of the precision and the tactile sense of the human hand. The arm is also less severely handicapped by bone necrosis and non-union and gross fibrosis of muscle, often occurring after radiotherapy particularly when these after-effects are situated in the upper arm, as is usually the case In these days of quest for better treatment, the patient with osteosarcoma of his arm has certainly more to lose by surgery and more to gain by the newer less tried methods It is primarily in the treatment of the osteosarcoma of the arm and those tumours in the inaccessible parts that we turn now for aid to the radiotherapist. And for the future surely there must be something better than either of these methods?

Chondrosarcoma

Phemister (1930) was the first to suggest the separation of this tumour from osteosarcoma and this is now accepted almost universally

Clinical Picture Clinically the separation is justified by the older age of onset, the slower rate of growth and the late appearance of metastases. Dahlin and Henderson (1956), in reporting a series of two hundred and twelve patients, showed that two-thirds of their cases occurred between 30 and 60 years of age, with a further fifty six cases distributed equally between the third and seventh decades. Only four cases occurred under 20. In this series, two-thirds of the patients were males (one hundred and thirty-eight males, seventy-four females) The rate of growth is, as a rule, much slower so that the life history of one of these tumours may extend over 10–15 years and any conclusion on the result of treatment must be based on a follow up of not less than 10 years. Metastases are rarely present when the diagnosis is first made, thus paving the way for a much improved prognosis A chondrosarcoma may develop secondarily on a pre-existing chondroma or osteochondroma, or may arise *de novo* In many cases, it is not possible to come to any conclusions on this point, particularly where a large chondrosarcomatous mass has already been formed. A chondrosarcoma presents either as a central or a peripheral lesion, and the radiological picture is described under these headings, although in some large tumours it is impossible to decide whether they are central or peripheral in origin. The bones most frequently involved are the pelvis, chest wall, and femur the scapula, humerus, tibia, fibula, and the vertebræ being involved less commonly The hands and feet are rarely involved.

Pathology Histologically this tumour (Fig. 197 (*b*)) largely consists of cartilage, although the matrix may undergo myxomatous change, calcification and ossification in places Although some tumours are evidently malignant, others present a real difficulty in deciding whether the histological picture is benign or malignant. The tell-tale evidence of malignancy is given by Lichtenstein (page 135) as "(1) many cells with plump nuclei (2) more than an occasional cell with two such nuclei and especially (3) giant cartilage cells with large single or multiple nuclei or with clumps of chromatin."

In any chondroid tumour arising in a patient over 20 years of age, one should always regard with suspicion of malignancy

(*a*) Large-celled cartilage

(*b*) Evidence of interstitial cell proliferation, i.e. groups of closely packed vacuolated chondrocytes.

(*c*) Absence of a well-defined and fairly typical perichondrium.

(*d*) Large areas of cartilage necrosis.

Furthermore whilst in osteosarcoma, mitoses are frequent in the typical tumour they are only occasionally found in many chondrosarcomata, the cells of which appear to divide amitotically

In connexion with the histological grading of chondrosarcomata, reference should be made to the paper by Thompson and Turner Warwick, (1955).

Lichtenstein and Jaffe (1943) contend that a careful study of many fields will always avoid the "underdiagnosis" of a chondrosarcoma as a chondroma. Many chondrosarcomata derive from pre-existing benign cartilaginous tumours, either an enchondroma or the cartilaginous cap of an osteochondroma Of the latter a case of Keith's aclasis

presents a bigger risk, presumably the result of the multiple lesions. Local recurrence after excision is a common feature in the history of a chondrosarcoma, where its slow growth encourages local excision which is only too often insufficiently radical. While

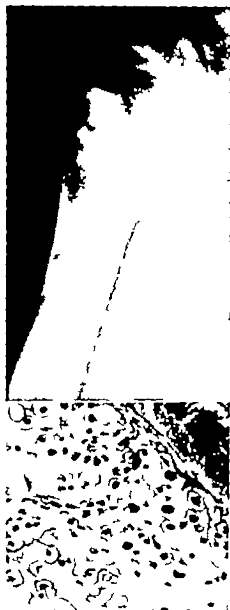


FIG. 197(*a*) CHONDROSARCOMA. Central Chondrosarcoma. B.T.R./670. F aged 68. This shows an osteolytic lesion, indefinite in outline, expanding and in places destroying the cortex. The tell-tale calcification reveals it as probably a cartilaginous tumour and the general picture is that of a central chondrosarcoma. The slow growth led to minimal symptoms, until the pathological fracture occurred.

FIG. 197(*b*). CHONDROSARCOMA. (H Ph. & T × 160). B.T.R./786. M aged 17. The growing edge of a chondrosarcoma showing the marked atypism of the chondrocytes. Cell division is usually amitotic, and tumour growth occurs both by appositional and interstitial cell proliferation. Some degree of matrix calcification (*bottom left*) is not uncommon.

metastases usually occur late in some cases there is a remarkable extension of the tumour into the veins and along them, to form neoplastic plugs in the vena cava or even the heart In spite of these intravenous extensions, metastases in the lungs may not have occurred. Metastases from chondrosarcoma occur rarely elsewhere than in the lungs, but lymphatic spread is sometimes demonstrated by involvement of the regional lymph glands.

Central Chondrosarcoma

This lesion manifests itself as a painful condition present over some months and often showing little in the way of clinical signs The upper end of humerus or femur are frequently involved and may show no evident tumour formation when first seen, although in the case of the ilium, the chondrosarcoma is more likely to have broken through the thin cortex to form a palpable mass.

Sometimes, in the long bones, the patient may present with a pathological fracture.

The radiograph (Fig. 197 (a)) reveals an osteolytic lesion with indefinite edges and usually slight expansion of the bone, an appearance which can only raise suspicion of a chondrosarcoma. When to this picture is added the tell tale flocculent calcification in the tumour there is some certainty of the diagnosis. The calcification in a central chondrosarcoma is, however usually much less marked than in the peripheral chondrosarcoma, due largely no doubt, to its smaller bulk.

Some of these central chondrosarcomata are derived from a recognizable pre existing benign cartilaginous deposit, localized or part of enchondromatosis (Ollier s disease) The short tubular bones of the hands, so frequently the site of enchondromata are, however extremely rarely the site of central chondrosarcoma

Peripheral Chondrosarcoma

This lesion develops peripherally and is occasionally recognizable as secondary malignant transformation in the cartilaginous cap or more central cartilaginous deposits of an osteochondroma, either a solitary lesion or part of the multiple osteochondromatosis of Keith s aclasis The osteochondroma may have been recognized for years and have shown no tendency to enlarge nor to cause pain. Then the tumour begins to enlarge and cause some discomfort, indicating a change in its nature A chondrosarcoma of the pelvis may be of considerable size before the patient presents himself for treatment, while the more rapidly growing recurrence, following inadequate local excision, may reach tremendous size encroaching on the true and false pelvis as well as protruding externally as a visible tumour Such a large, slowly growing tumour of the innominate bone is fairly typical of a peripheral chondrosarcoma, and a neoplasm with similar features occurs occasionally in the scapula (Fig. 198) Both usually show much calcification. Bones in which peripheral chondrosarcoma most commonly occurs are the innominate, the scapula, the ribs and the long tubular bones, where osteochondromata are commonly found.

The main feature of the radiograph is the large soft tissue shadow with scattered areas of calcification, suggestive of a snow storm, and the irregular edge of the bone or of the occasional osteochondroma, from which the sarcoma arose—later to show considerable destruction of bone by the neoplasm.

Treatment. Until quite recently treatment would have been considered as essentially surgical, but the remarkably lethal effects of the modern powerful radiotherapy even on osteosarcoma, must make one consider this alternative treatment. The question has been more fully dealt with under Osteosarcoma, and there is only need here to add that in a chondrosarcoma we have a tumour more amenable to cure by surgical removal, and a mass of tumour more likely to give trouble from necrosis and non-union following radiotherapy Therefore, with few exceptions, surgery is to be recommended.

presents a bigger risk, presumably the result of the multiple lesions. Local recurrence after excision is a common feature in the history of a chondrosarcoma, where its slow growth encourages local excision, which is only too often insufficiently radical. While

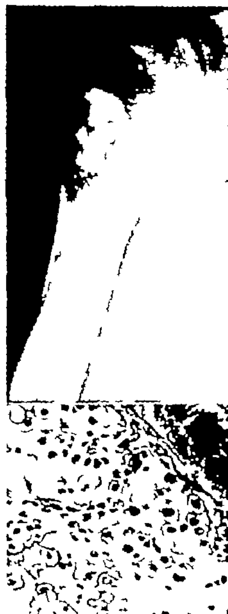


FIG. 197(a). CHONDROSARCOMA. Central Chondrosarcoma. B.T.R./670. F aged 64. This shows an osteolytic lesion, indefinite in outline, expanding and in places destroying the cortex. The tell-tale calcification reveals it as probably a cartilaginous tumour and the general picture is that of a central chondrosarcoma. The slow growth led to minimal symptoms, until the pathological fracture occurred.

FIG. 197(b). CHONDROSARCOMA. (H.Ph. & T. × 160) B.T.R./786. M. aged 17. The growing edge of a chondrosarcoma showing the marked atypism of the chondrocytes. Cell division is usually amitotic, and tumour growth occurs both by appositional and interstitial cell proliferation. Some degree of matrix calcification (*bottom left*) is not uncommon.

metastases usually occur late in some cases there is a remarkable extension of the tumour into the veins and along them, to form neoplastic plugs in the vena cava or even the heart In spite of these intravenous extensions metastases in the lungs may not have occurred. Metastases from chondrosarcoma occur rarely elsewhere than in the lungs, but lymphatic spread is sometimes demonstrated by involvement of the regional lymph glands.

Central Chondrosarcoma

This lesion manifests itself as a painful condition present over some months and often showing little in the way of clinical signs. The upper end of humerus or femur are frequently involved and may show no evident tumour formation when first seen, although in the case of the ilium, the chondrosarcoma is more likely to have broken through the thin cortex to form a palpable mass.

Sometimes, in the long bones, the patient may present with a pathological fracture.

The radiograph (Fig. 197 (*a*)) reveals an osteolytic lesion with indefinite edges and usually slight expansion of the bone, an appearance which can only raise suspicion of a chondrosarcoma. When to this picture is added the tell tale flocculent calcification in the tumour there is some certainty of the diagnosis The calcification in a central chondrosarcoma is, however usually much less marked than in the peripheral chondrosarcoma, due largely no doubt, to its smaller bulk.

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Surgery should be applied as an amputation or a generous local excision the tumour of the ribs can only be treated by the latter while a hindquarter amputation from the point of view of radical surgery to a tumour of the pelvis is little more than a wide excision. While there are reports of a number of long term survivors following surgical procedures less than amputation, we are dealing with a potentially lethal tumour and it is rarely that one can advise conservative surgery We must adopt the concept that there is *but one good chance of curing most chondrosarcomata*, particularly those

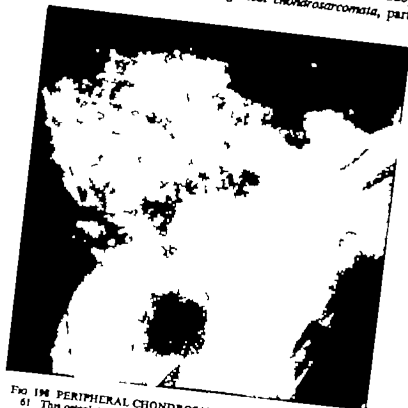


FIG 198 PERIPHERAL CHONDROSARCOMA. B.T.R./119 M aged 61 This osteolytic lesion of the scapula with large soft tissue tumour shows the flocculent calcification, typical of a cartilaginous tumour These radio-opaque deposits are amorphous and show none of the structure seen in bone formation.

of the trunk and the upper ends of the femur and humerus, in which sites, according Dahlin and Henderson, 84 per cent of these tumours occur In the elderly and in th upper arm in particular a local excision with or without a bone graft must be considerec The retention of function must be weighed against the increased risk excision o scapula or upper end of humerus are justifiable procedures in certain localized chondro-sarcomata involving these bones. Dahlin and Henderson do well to stress the risk of tumour implantation in surgical wounds and the need to remove a chondrosarcoma, including any biopsy scar in one block in such a resection. Survival over many years has been reported after curettage of the tumour *but this procedure is inadequate for a chondrosarcoma*. Reliance on a combined programme of surgery and radiotherapy is

unsatisfactory Irradiation will not salvage the results of an operation ill conceived ill planned, or badly performed.

Fibrosarcoma—Central Fibrosarcoma of Bone

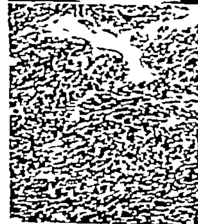
This is the third group of the osteogenic series of bone tumours, a group in which Macdonald and Budd (1943) were able to show a 60 per cent chance of survival The fibrosarcomata however vary in malignancy a few presenting all the features of a rapidly invasive malignant neoplasm. The tumour usually occurs in the large limb bones and occasionally may grow slowly presenting as a painful lesion with few physical signs in an early case. Pathological fracture is not infrequent. The radiograph (Fig 199 (*a*)) shows an osteolytic area in the medulla, with indefinite edge and perhaps erosion of the cortex over which may be some focal periosteal reaction clearly a malignant lesion. Foci of calcification do occur but are not a conspicuous feature as in chondrosarcoma. The radiograph does not allow of a firm diagnosis, which is obtainable only after biopsy

Pathology The histology (Fig. 199 (*b*)) presents a picture of interwoven bundles of collagen fibres with the prognosis of the particular lesion revealed by the cells, whether they are uniform and mature in appearance, as in the less malignant, or are pleomorphic, showing much nuclear activity with many bizarre giant cells—features of such fibrosarcomata as may occur in Paget's disease. Metastases usually occur in the lungs. In the Bristol series of twenty six sarcomata complicating Paget's disease, this is the commonest histological variant.

Treatment. The remarks on treatment of chondrosarcoma apply equally to fibrosarcoma. While amputation is the safest procedure, conservative surgery is occasionally justified.



(*a*)



(*b*)

FIG. 199(*a*). FIBROSARCOMA B.T.R./338 M aged 61 This radiograph shows a fibrosarcoma at the lower end of the shaft of a humerus, the middle third of which reveals evidence of Paget's osteitis deformans. The tumour appears to be slowly growing from the complete disappearance of the original shaft outline Although it is primarily osteolytic, there is new bone formation, as a rule clearly outlined.

FIG. 199(*b*) FIBROSARCOMA. (H. & E. × 160) B.T.R./597 M aged 31 The tumour consists of densely packed compressed fusiform cells. The amount of fibrous stroma may vary considerably In this instance, there is only delicate network of fine collagenous fibres orientated in the long axis of the tumour cells.

Radiotherapy at this stage of our knowledge, appears indicated in the treatment of lesions of the arm, allowing the limb to be preserved. The frequent necrosis and non-union of pathological fractures occurring in lesions treated by high-voltage irradiation do not present the serious problem in the arm that they do in the leg.

Parosteal Fibrosarcoma

A mention should be made of the rare tumour the parosteal fibrosarcoma, which is similar in nature and prognosis to the fibrosarcoma of other soft parts. Some of these tumours may be of neural origin. Usually growing very slowly it affects the bone only by pressure erosion when the tumour has grown to some size. This is not a tumour of bone and will not, therefore, be further considered here

Malignant Osteoclastoma

The Grade III tumour occurs in from 10 per cent (Murphy and Ackerman) to 15 per cent (Lichtenstein, page 107) of osteoclastoma series and these constitute the malignant variant. The use of biopsy is to be advised in the investigation of any possibly malignant growth, and in no tumour more so than a suspected osteoclastoma The grading of the histological section will do much to map out the prognosis and point to the treatment. Clinically the more rapid growth and atypical radiographic appearances may suggest malignancy and the occurrence of an osteoclastoma in the presence of Paget's disease (Russell, D S., 1949) is more than suspicious.

The radiograph (Fig. 200 (a)) yields much less help than might be expected, as lesions in which there is marked expansion with almost complete disappearance of the cortex often prove to be innocent, and, on the contrary malignancy may be present where the skiagrams of the tumour give no indication of such. Possibly the only useful positive radiographic sign is rapid extension of the radiolucent lesion with concomitant bone destruction.

Pathology The grading of osteoclastomata on histological grounds has been advocated by Lichtenstein (page 107 *et seq*), and his findings have been corroborated by other workers in this field. One must, however point out that both Willis (page 864 and 1949) and Russell (*supra*) have contended that tumours which are eventually frankly malignant may not initially show a histological appearance differing from that of the innocent lesion. Lichtenstein (page 107) contests this view Be that as it may the literature contains well-documented cases of osteoclastomata where recurrence and metastasis have arisen from growths histologically interpreted as benign in nature. These few exceptions should not undermine confidence in the value of the estimation of innocence or otherwise if carried out by an experienced person.

The Grade I lesion shows no atypism of the stromal cells which are not packed too closely and usually tend to a spindle shape Some collagenous stroma may be found. The giant cells are numerous and have many nuclei and these resemble the nuclei of the stromal cell Some few of these growths may recur after treatment.

The Grade II lesion (Fig. 193 (b)) shows some atypism in the stromal cells, which are more closely packed many tend to an oval shape and the nuclei show more activity by hyperchromatism, an occasional double nucleus, and even mitoses The giant cells show nuclear changes in line with those of the stromal cells. Tumours of Grade II tend strongly

towards recurrence and some of them do eventually undergo malignant transformation, although usually only after an interval of some years (Lichtenstein, page 111)

In Grade III Fig. 200 (*b*) which constitutes the malignant osteoclastoma, the stromal cells are plump, packed closely together often in a whorled arrangement the nuclei show



FIG. 200(*a*). MALIGNANT OSTEOCLASTOMA. B.T.R./423 F aged 35 Radiograph showing the extension of the lesion in the six months prior to biopsy This rapid growth is probably the only reliable radiological sign of malignancy The lesion was not controlled by local surgery nor by radiotherapy and the leg was amputated eighteen months later

FIG. 200(*b*). MALIGNANT OSTEOCLASTOMA. (H.Ph. & T × 160). B T R./423 F aged 35. Although certain areas of this tumour show many large multinucleated giant cells of innocent appearance, the stromal cells are pleomorphic with relatively frequent mitoses. These latter features, whilst not very readily appreciated, indicate neoplasm of histological Grade III

much activity and atypism. The giant cells are small, containing few nuclei which show the irregularities seen in the stromal cells, and the latter may show more frequent mitoses. Although an osteoclastoma may present as a Grade III lesion, it more often shows changes through the years from an appearance of Grade I or Grade II each recurrence showing a more malignant tendency Some lesions may develop the picture of an osteogenic sarcoma or a fibrosarcoma, and metastases in the lungs have shown new bone formation

(Russell, 1949) The tumours of Grade III metastasize sooner or later particularly to the lungs (Lichtenstein, ibid.)

Treatment. A malignant osteoclastoma is best treated by amputation where feasible. Extensive bone destruction and joint involvement strongly indicate amputation. The prognosis is particularly serious in the rare case complicating Paget s disease, but in all, the outlook is grave, although metastases may not have already occurred when the diagnosis is first made The modern powerful radiotherapy may succeed in some cases the lesion is rare but cases not amenable to amputation from their very situation do present and give opportunity for trying out the newer methods of treatment. Instances have recently been reported where an apparently isolated pulmonary metastasis has been successfully removed by a wedge resection of the lung (Murphy and Ackerman, 1956).

Ewing's Sarcoma

This tumour according to Ewing (1921 1924), has certain characteristics—youth of the patient characteristic radiographic appearance of osteolytic lesion and reactive periosteal new bone laid down in *onion-layers* marked and rapid response to radiotherapy—to be followed by local recurrence and metastases in other bones and lungs in all but a very small minority of cases.

Great controversy has raged over this tumour some denying the existence of this neoplasm, others accepting the entity as described above, and still others accepting Ewing's tumour but denying that the above features are in the least characteristic. Willis (pages 687 and 1940), *inter alios* doubts the very existence of Ewing s tumour as a pathological entity pointing out with all justification the inadequate documentation and inconclusive evidence of many published cases in few of which an autopsy was performed. Together with Colville (1933) and other histologists, he has demonstrated that many so-called "Ewing s tumours" were in fact examples of metastatic neuroblastoma. Other writers have been equally convinced that this tumour is in fact a type of reticulum-cell sarcoma.

Coley Higinbotham, and Bowden (1948) accept the diagnosis of Ewing s sarcoma and attach importance to the features originally described by Ewing, while Lichtenstein and Jaffe (1947) concluded that a small number of their cases—seventeen—must be accepted as Ewing s tumour but that on this clinical material the various classical characteristics of this aggressive neoplasm could not be accepted as a sure basis on which to build the diagnosis only four of their cases were confirmed by autopsy

While it must be admitted that in the present state of our knowledge no case of Ewing's sarcoma can be accepted as authenticated without a very detailed autopsy having been performed, it seems worth while referring to the clinical and pathological features of cases which would still be accepted by many

Clinical Features. The age is likely to fall between 10 and 25 years, males being rather more common

The tumour is usually situated towards the centre of the shaft of a long bone but can occur in any bone

Pain as the outstanding symptom, and tumour as the outstanding sign, conform to the pattern of most malignant bone tumours Some degree of pyrexia has been found in these cases and Lichtenstein and Jaffe have endorsed this in their series, although

attaching a prognostic importance to this feature as indicating the probability of death within a few months. A high blood sedimentation rate is also a bad prognostic omen.

Radiographic Features. The only characteristic feature is an osteolytic lesion (Fig. 201 (*a*)), often very patchy but sometimes fairly circumscribed. A certain amount of reactive bone may be laid down in three to four even laminæ of periosteal bone, over lying this osteolytic lesion—the so-called "onion skin" appearance this picture is not common and certainly cannot be relied upon even when present (Sherman and Soong, 1956). A search must always be made for secondaries in other bones or in the lungs The diagnosis remains very tentative, and even after biopsy must be accepted as unconfirmed while life precludes the only thorough investigation of such cases.

Pathology In the gross, these tumours will be found to present considerable masses outside the bone and to extend along the bone and medullary cavity further than suspected from the clinical and radiological picture. Liable to hæmorrhage and necrosis, the tumour may be considerably altered by such features.

Histologically (Fig. 201 (*b*)) the tumour cell is, of course, round or oval and necessitates the differentiation of the tumour from neuroblastoma, anaplastic carcinoma, multiple myelomatosis, malignant lymphoma and reticulum cell sarcoma. The cell is characterized by an *indefinite outline, relatively scanty cytoplasm* and a large nucleus, two or three times the size of that of a lymphocyte, with scattered chromatin The cells are not packed very closely together and often show a perithelial arrangement around a central blood vessel The "pseudo-rosettes," sometimes seen result from



FIG 201(*a*). EWING'S SARCOMA. B T R./20. F aged 5 The radiograph shows a purely osteolytic lesion apart from periosteal reactive bone as shown by onion-skin appearance on the medial side, with "Codman's triangles superimposed upon the lateral cortex at the limit of the lesion. The cortex is eroded. Note the situation of the lesion in the middle of the shaft. With radiotherapy the humerus became indistinguishable from a normal bone. Subsequently there was local recurrence followed by dissemination and death of the patient.

FIG 201(*b*). "EWING'S SARCOMA. (H & E. × 340) B T R./245. M aged 16 A representative area of the ominous so-called Ewing's Tumour" of bone. The small round or oval cells are so featureless that any precise designation for such a tumour is conjectural and highly controversial.

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necrotic cells surrounded by living ones and create further confusion between this tumour and neuroblastoma.

The origin of the tumour cell is still in doubt. Lichtenstein and Jaffe, and Oberling, feel that it is closely related to the reticulum cell, but Ewing's conclusions that it was of endothelial origin now have little support. In many instances, the histological structure is so featureless that any precise histological diagnosis is highly conjectural. That being so until conclusive evidence has been produced of the exact nature of this debatable tumour the retention of the eponymous title for a *clinical entity only* would appear to be permissible.

Treatment. While a case accepted as a Ewing's tumour on clinical, radiographic, and possibly histological grounds will by its radiosensitive response help to confirm the diagnosis, local recurrence is the rule and the few survivors tend to come from amputations.

The prognosis in the past has been wholly unreliable owing to the heterogeneous group of round celled osteolytic lesions grouped under this heading. Nevertheless, with lesions which present with the clinical and radiographic features mentioned above, and in which the histo-morphology is that of an undifferentiated round or oval cell tumour all seem agreed about the evil prognosis, whatever views may be maintained of the nature of the neoplasm. Coley and his co-workers have recently reported a 5 year survival rate of 4 per cent, stressing the very grave outlook.

Multiple Myeloma

This is probably the commonest primary malignant tumour of bone, presenting as a solitary myeloma (rarely), multiple lesions or a diffuse infiltration of many bones. Although at one time it was thought the former was an entity apart, it is now felt that the solitary myeloma is almost invariably but the first sign of the more widespread myelomatous conditions, although there may be a long latent period of some years before the multiplicity of the osteolytic lesions becomes apparent. Very rarely indeed an entirely local myeloma appears to occur apart from any subsequent myelomatosis (Raven and Willis, 1949). The malignant change occurs in hæmopoietic tissue contained within the bone, and very occasionally similar malignant tissue has been found in extra-skeletal tissue alone

The common myeloma is the plasma celled myeloma, but very occasionally myelomata of other types may be encountered Lichtenstein (page 242) is of opinion that these merely represent stages of maturation of the basic cell represented by the usual plasma celled lesion. The condition often virtually involves the entire skeleton and may produce lesions in the spleen, liver lymph nodes, and very occasionally other organs

It occurs rather more commonly in men, often over 60 years of age, rarely under 30 years. The presenting symptom is pain, frequently followed in a few weeks by an exacerbation from a pathological fracture this picture being most commonly seen in the spine, where a pathological crush fracture in a man over 50 years of age is quite often to be explained by multiple myelomatosis. Occasionally the case presents as a tumour of bone or a pathological fracture in one of the long bones of the limb. The general health of the patient is frequently already impaired, although in others it is, as yet, unaffected. However loss of weight, malaise, and vague general aches and pains are soon added to the clinical picture Occasionally the solitary lesion may remain the

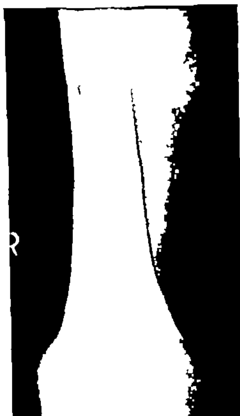


FIG. 202(*a*). MYELOMA. B.T.R./333. M. aged 50. The lower half of this femur shows two osteolytic lesions, indefinite in outline. The diagnosis, in this man of 50 years of age, was most probably multiple myeloma or metastatic carcinoma. Further clinical and radiological investigation or biopsy were required to indicate the precise nature of these tumours, which proved to be myelomata.

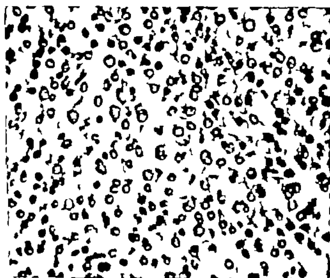


FIG. 202(*b*). MYELOMA. (H. & E. × 360.) B.T.R./672. F. aged 73. Characteristic field in which the plasma cell appearance of some tumour cells may be noted. There is a small amount of amorphous intercellular stroma, but collagenous fibres are noticeably absent.

sole abnormality and the patient remain in good health for years after its removal It is now believed that eventually widespread involvement will occur with very few if any exceptions.

Radiologically the lesion reveals itself as either a compression fracture of the spine, or one or more osteolytic areas with indefinite edges suggesting malignant infiltration (Fig. 202 (*a*)) Search must be made for other foci in the skeleton, the skull, ribs and pelvis being the most likely sites.

Diagnosis. Besides the possible help provided by radiographs of the skull and pelvis and any other bone from which there may be complaints, assistance in diagnosis will be obtained by

(1) Estimation of blood proteins and a study of electrophoretic patterns.
(2) Blood sedimentation rate
(3) Examination of urine specimens for Bence Jones proteose
(4) Marrow biopsy
(5) Biopsy of the lesion.

In a case of the so called "solitary myeloma," the first four tests will probably be negative and the biopsy will yield the diagnosis but with the more generalized condition, the *blood sedimentation rate will be found to be markedly raised*—up to 100 mm. in 1 hour or more—the blood protein will be much increased from the addition of the abnormal globulin, thus reversing the normal albumen/globulin ratio of 2 to 1 The abnormal globulin stains as a dark band on filter-paper electrophoresis of the plasma (Fig. 203 (*a*)), and an identical band may be demonstrated by electrophoresis of the urine when the proteose is being excreted (Fig. 203 (*b*)) It is this globulin that gives the Bence Jones proteose reaction in a percentage of cases, much more commonly (35 per cent) in the later stages of the disease than earlier when it would be such a help in diagnosis. Whilst the changes in protein distribution in the plasma are very useful confirmatory evidence it must be borne in mind that similar abnormalities may also obtain in other diseases where there is extensive bone destruction. Marrow biopsy may help and may confirm the widespread involvement of the skeleton.

Gross anæmia may be detected fairly early in the history renal changes and occasionally amyloidosis feature in the later stages.

Pathology The bones are infiltrated with pinkish-white neoplastic tissue, tending to perforate the cortex and form extraosseous masses in places. The histology (Fig. 202 (*b*)) of this tumour usually shows closely packed cells containing nuclei almost filling the cell. The chromatin is arranged in granules often resembling a cartwheel, hence the term "plasmacytoma" from the similarity of plasma cells. Certain pathologists do not agree that these are plasma cells but some primitive cell of myeloid or hæmic origin. They point out that certain cases clinically and radiologically typical, yield tissue sections of larger celled type with relatively smaller nuclei, while the rarer types classified as myeloid, erythroblastic and lymphoid types are surely only cases showing cells of greater or less maturity Bi- and tri-nucleate cell forms may be found, and tumour giant cells are not infrequent.

Treatment. It is only rarely that more can be done for a patient with multiple myeloma than palliation. It can be hoped that treatment may possibly effect a cure in the ostensibly solitary myeloma. It is justifiable to amputate in such a case, even though

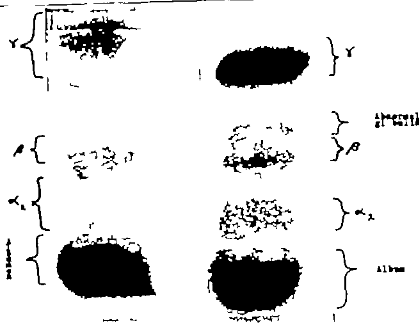


FIG. 203(*a*). MULTIPLE MYELOMATOSIS. Electrophoretic patterns obtained with normal serum compared with that obtained with serum from a case of multiple myelomatosis. The latter shows considerable increase in α globulin and the presence of an abnormal slowly moving β globulin.

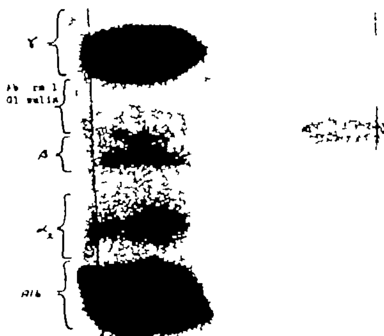


FIG. 203(b). MULTIPLE MYELOMATOSIS. Electrophoretic patterns of serum and urine in a case of multiple myelomatosis. These were obtained simultaneously and show that the "proteose" in the urine moves at the same rate as the abnormal β globulin. The inference is that this substance alone is excreted by the kidney.

Radiologically (Fig. 204 (*a*)) the lesion presents as an irregular destructive lesion, starting in the medulla, usually of a long bone. The cortical bone reaction is scanty or absent. There is a tendency to spread along the length of the bone, but penetration of the cortex and a soft tissue tumour are late

Pathology The lesion (Fig. 204 (*b*)) consists of polyhedral or round cells with large vacuolated nuclei, showing coarse chromatin and a single prominent eosinophilic nucleolus sometimes the cell boundaries are very indefinite and the well chosen silver preparation often shows fine reticulum fibres between individual cells, forming a well-developed network. However this special feature is unreliable, many of the more aggressive tumours, in which the cells appear symplasmic, are practically devoid of reticulin, save for that which may persist around small blood vessels, coarse septate strands, and residual material from invaded tissues. There is often considerable pleomorphism, and numerous mitoses may be seen.

Treatment. Radiotherapy is the treatment of choice. The tumour responds readily to radiotherapy and the results are as good as those following amputation, without the consequent mutilation. The extension of the tumour up and down the bone, far beyond its clinical and radiological limits and the frequent involvement of the regional lymph glands, must be given full weight when planning treatment.

Chordoma

This rare tumour develops from the remains of the notochord and in 90 per cent of cases occurs at one or other end of it, in the region of the spheno-occipital synchondrosis or of the sacrum and coccyx. Growing very slowly it may reach a great size, producing symptoms from erosion of and pressure on, important structures—intracranial or pelvic—as well as on nerve roots passing through the tumour mass. The bone is destroyed and replaced, and similar invasive action occurs in surrounding soft tissue structures.

Although sometimes occurring in children, it is usually encountered in late adult life, twice as often in males as in females.

A radiograph (Fig. 205 (*a*)) shows destruction of the affected bone or bones, usually with some expansion and occasionally a lobulated appearance.

The pathology reveals a lobulated solid tumour occasionally cystic in places, with a fibrous capsule On section it often shows a mucinous or gelatinous cut surface.

The origin of the notochord has been the subject of controversy and though it has in the main been regarded as a mesodermal structure, it has very close associations with both ectoderm and endoderm. It is not surprising, therefore, that chordomata may have a very complex histology The tumour may show much "epithelioid" tissue, or even resemble a sarcoma, depending presumably upon which of the three primary germ layers has the predominant role as also upon the degree of anaplasia. In all cases there is, however a considerable element of mucinous intercellular matrix, and areas (Fig. 205 (*b*)) showing large pale staining vacuolated mucin containing cells, known as "physaliphorous" cells, which are characteristic of chordoma. In the sacral area, one must remember that colloid carcinoma of the large bowel, when presenting as a large mass, may be taken for a chordoma, or vice versa. It is to be noted that while a chordoma is usually only slowly growing and locally invasive, Willis (page 923) states that metastases have been reported.

Treatment consists of local removal, unfortunately only too frequently incomplete



FIG. 205(*a*). CHORDOMA. B.T.R./4. F. aged 5. We are presented with destruction and expansion of the lower two lumbar vertebræ and of the upper segments of the sacrum with a loculated appearance. *The moulding of the bones implies slow growth,* and in this situation chordoma is the most probable diagnosis.

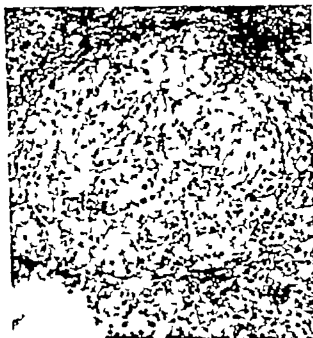


FIG. 205(*b*). CHORDOMA. (H. & E. × 105). B.T.R./30. M. aged 48. A typical area showing the large vacuolated "physaliphorous" cells. In some areas the cell outlines are ill-defined, thus giving the appearance of a diffuse multinucleated syncytium.

on account of the involvement of the pelvic organs and sacral nerves or even more vital structures in the base of the skull. Chordomata show little response to radiotherapy although it is sometimes of help for palliation in late cases with much pain. On the whole, chordomata tend to be diagnosed late in their life history presenting as large tumours, and the prognosis is very unsatisfactory although relief of symptoms for some years is often possible by resort to surgery

Liposarcoma and Angiosarcoma

These tumours have been reported and are included for completeness. There is no general agreement as to the pathological features of the Liposarcoma.

The rare case of Angiosarcoma presents a serious prognosis despite radical treatment.

SECONDARY MALIGNANT TUMOURS IN BONE

As it is by far the *commonest malignant tumour in bone* a metastasis must always be considered in any tumour of bone even, for example when florid Paget's disease is also present. Many mistakes have resulted from failure to recognize this possibility

Carcinoma

The breast is, undoubtedly the commonest source of a neoplasm, metastasising to bone but the lungs, prostate, kidneys, thyroid and the stomach are also frequent sites. No organ could be excluded from a complete list, and the frequency of these metastases in the spine has been estimated as 27 per cent (Abrams, Spiro, and Goldstein), but it is only in the later stages, and particularly with pathological fractures, that these deposits reveal themselves. Some pain may be caused, and the radiograph both in vivo and in vitro may give no suggestion of malignant invasion, yet the vertebra on being cut across will show large deposits of neoplasm, clearly recognizable to the naked eye. Metastases are usually osteolytic, with carcinoma of the prostate as the outstanding example of the osteoblastic metastasis, although other carcinomata do occasionally cause osteoblastic secondaries. The typical osteolytic lesion (Fig. 206) presents in a radiograph as an area of rarefaction, indefinite in its edge and characteristically provoking no new bone formation, and eroding indiscriminately the cortex or medulla. The vertebræ, pelvic bones, femora, and the ribs are frequently involved, and not uncommonly the skull. Sometimes the diagnosis is made following a biopsy of the bone tumour but on many occasions a search for a possible primary tumour brings this to light, and identification of this tumour may be more easily obtained.

Treatment. Palliative treatment is usually all that is called for Only very occasionally—perhaps in a case of hypernephroma or malignant thyroid—it is justifiable to remove the primary neoplasm and the apparently single metastasis by amputation. The hope of lasting benefit is slight, but a long latent period may result. Radiotherapy to primary and secondary growth may be equally beneficial. Even in the presence of marked destruction with a pathological fracture it is remarkable how these fractures sometimes unite following irradiation, to give a limb capable later of weight-bearing without splintage

Metastases from the prostate like the parent tumour are usually "hormone dependent" and can, to some extent, be controlled by Stilboestrol Similarly with

carcinoma of the breast there is frequently considerable hormone dependence" and these can be influenced favourably by Testosterone usually given to patients before the menopause, or by Stilboestrol administered to older cases after the menopause. The treatment remains somewhat empirical and the response to treatment can never be foretold in any given case Along similar lines has developed the recent work with adrenalectomy and oöphorectomy where quite spectacular results have been obtained some patients with a number of metastases recovering sufficiently to return to work



FIG. 206. CARCINOMATOUS METASTASIS. B.T R./418. M. aged 46 This radiograph reveals a purely destructive lesion with irregular indefinite edge. A metastatic carcinoma is the most *probable* diagnosis although multiple myelomatosis must be considered. A radiograph of the chest revealed a primary carcinoma of the bronchus.

with few complaints, while the radiographic metastases dwindle or disappear The improvement can be quite dramatic, although always temporary the average post operative survival being 2–2½ years (Cade)

Neuroblastoma

These tumours occur in young children and frequently metastasize to bone, from whence come the presenting symptoms of pain and loss of function.

The appearance in the radiograph (Fig. 207 (*a*)) is of a destructive lesion, mottled and ill-defined, but often showing marked periosteal reaction in the form of sun ray spicules and sometimes the formation of onion layers. Several bones may be involved and the clinical, radiological and pathological pictures (Fig. 207 (*b*)) are such that the conclusive diagnosis of this neoplasm is only possible after a full autopsy has been carried out. In the past, secondary neuroblastoma has frequently been mis-diagnosed as a Ewing's tumour A major surgical assault on the primary tumour has resulted in apparent cures and massive doses of vitamin B_{12} are also establishing a reputation in the treatment of a tumour formerly considered as virtually incurable Temporary relief of symptoms and marked shrinkage of the tumour typically occur with radiotherapy



FIG. 207(a). METASTASES FROM NEUROBLASTOMA. B.T.R./676. M aged 3. Both femora show extensive destructive lesions involving cortex and medulla with large soft tissue tumours. There is spiculated new bone formation of the left femur and reactive tri-angles at the upper limit of the lesion in the right femur

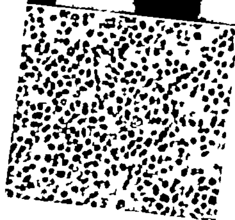
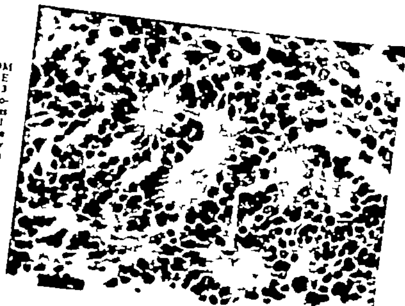


FIG. 207(b). METASTASES FROM NEUROBLASTOMA. (H. & E. × 300) B.T.R./676. M aged 3. This is representative of the common histomorphology of this tumour. The small rather densely packed cells are often featureless, but may sometimes show "rosette" arrangement, or even a tendency to a trabeculated pattern.

FIG. 207(c). METASTASES FROM NEUROBLASTOMA. (H. & E. × 380) B.T.R./967. M aged 3. The so-called rosettes of neuroblastoma showing the fibrous nature of the central material. The fibres can sometimes be traced back to cells which may show "tadpole" shape. From the femoral metastasis of an autopsied case, in which a primary neuroblastoma of the left suprarenal gland was found.

(*By courtesy of Dr. J. C. [illegible]*)



Hodgkin's Disease

Hodgkin's disease, which usually affects young adults, most commonly men, may also involve the skeleton The radiographic picture is not diagnostic, resembling that of other osteolytic secondary lesions in bone. Any reticulosis with widespread bony secondary lesions will give a similar picture.

It is only possible to offer palliation radiotherapy radio-active phosphorus nitrogen mustard, and urethane have been used to this end

Malignant Synovioma (Synovial Sarcoma)

Synovial tissue is modified connective tissue and will be found in normal anatomical sites, or may be newly formed as in adventitious bursae and pseudarthroses. It is, therefore, not surprising to find that synoviomata may develop well away from joints (Fisher 1942 King, 1952) and "usually outside these structures although often in close proximity to them" (Haagensen and Stout, 1944) King (1952) has pointed out that the tumour is best classified on histological and not on a histogenetic basis. Certain clinical and radiological features are found to correspond with this histological picture to constitute the entity—a "synovioma." The not infrequent involvement of bone by synoviomata, particularly in the region of the knee joint, is the justification for briefly referring to this tumour in this chapter

Clinical Features. Pack and Ariel (1950) have reported malignant synovioma as comprising about 8 per cent of a large series of soft tissue sarcomata. It is noteworthy that although the great majority of benign synoviomata occur in the hand, the malignant counterpart is 3 to 4 times more common in the leg, with the most frequent site of occurrence in the vicinity of the popliteal space and knee joint

The tumour may arise at any age (9 months to 70 years being reported), but the majority appear during the third and fourth decades. Most published series report a preponderance of male patients of the order of 2 1

The usual clinical picture is the presence of a slowly growing swelling of recent origin, although some have been insidious in onset or present for many months, with more recent rapid enlargement. Involvement of the regional lymph nodes is not infrequent, and there may also be invasion of the adjacent bones, or even skeletal metastases. Pain is not usually a prominent symptom.

Radiographically (Fig. 208 (*a*)) there may be no discernible changes, or one may find an area of irregular osteolysis accompanied by a soft tissue shadow showing focal calcification. In the related joint there may also be enlargement of the joint capsule

Pathology Macroscopically there is considerable variation in appearance of this tumour some being well circumscribed, others ill defined and irregular The tumour tissue is usually solid and of a pinkish/white or greyish colour but may also be cystic or mucinous. Microscopically (Fig. 208 (*b*)) the tumour most often shows a collagenized spindle cell structure with fairly numerous mitoses. Intermingled with this may be tissue clefts lined by polyhedral cells resembling synovium, together with foci of giant cells or calcification. For full details the reader is referred to the excellent paper of Wright (1952)

Treatment. The treatment of malignant synovioma is surgical, and in view of the bad experience with tumours of the lower limb amputation (with wide excision of

regional lymph nodes) is generally to be preferred (Haagensen and Stout, 1944). Wright (1952) reports 71 per cent of local recurrence in twenty four cases where there was only excision of the tumour Furthermore, although that writer emphasizes the correlation between prognosis and good histological differentiation of the tumour this conclusion is not universal (see King, 1952) Lichtenstein (1955) also describes the tumour as

(a)

(b)

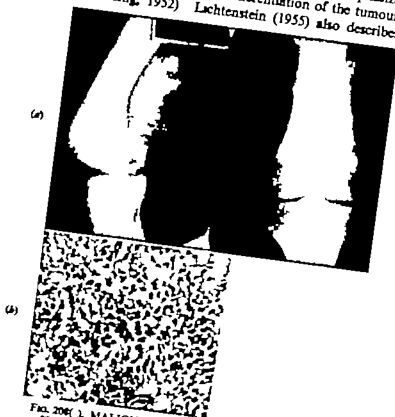


FIG. 208( ). MALIGNANT SYNOVIOMA. B T.R./89 F aged 32. The radiograph reveals extensive flocculent calcification in the soft tissue tumour There is considerable involvement of the medial femoral condyle. This is the picture seen five years after surgical removal of a malignant synovioma and stresses the treacherous nature of the tumour and the usual result following local excision.

FIG. 208(b) MALIGNANT SYNOVIOMA. (H & E. × 120). B T R./640 F aged 63 The chosen field shows typical features of synovioma, viz., spheroidal cells of moderate size distributed through a dense collagenised stroma in which are many tissue clefts In this, and in other tumours of the group, some parts showed a fibrosarcomatous appearance.

"treacherous," and cites examples of recurrence after a 5 or even 10 year period of quiescence In discussing the expediency of conservative surgical measures for some tumours, he advocates the use of prompt post-operative radiotherapy as a rational attempt to destroy any residual tumour cells.

Irradiation Sarcoma

Since the first case of bone sarcoma following irradiation by X-rays was reported by Beck in 1922, there has been an expanding literature on this topic. Wolfe and Platt

(1949) reporting two such sarcomata of the nasal bone, estimated that there was a total of sixty-two cases reported in the combined European and American literature. A further series of seventeen examples have recently been published by Sabanas *et al* (1956).

These sarcomata comprise five groups:

(1) Those following irradiation of tuberculous joints and other arthritic conditions.

(2) Those associated with ingestion of radium and reported by Martland (1931).

(3) Cases of late appearance of sarcoma (fibro-chondro- or osteo-) following irradiation of a pre-existing known benign lesion. Such cases have been reported by Cahan *et alia* (1948) and by Hatcher (1945).

(4) Neoplasms arising *de novo* in presumed normal bone which has been irradiated —as reported by Spitz and Higinbotham (1951), and by Carroll *et alia* (1956).

(5) Extraskeletal osteogenic sarcoma arising in irradiated soft tissues, as described by Auerbach *et alia* (1951).

There are certain similarities which occur throughout these several groups. These may not be constant, but are sufficiently frequent to be noteworthy.

(1) Latent period between exposure to radiation and presentation of sarcoma. In the thirty-nine cases considered by Jones (1953) this was 3–22 years, with a mean period of 8·6 years.

(2) Concomitant evidence of X-ray damage to tissues, e.g. radiodermatitis.

(3) Reported ages of patients was 9–62 years, with slightly higher incidence during the second and third decades.

(4) The sarcoma may arise in any bone, although, as with other forms of sarcoma, there is a predilection for the long limb bones—femur, tibia, and humerus.

(5) It has been generally concluded that sepsis is *not* a factor in the causation of irradiation sarcoma.

Dosage. In some cases, this has been clearly excessive, e.g. 25 000 röntgen units of X-radiation in 2 years to a skull. In the majority of instances, dosage has been considerably above an estimated tumour dose of 3 000 r, but from the literature it is quite impossible to indicate clearly the lowest dose of X-radiation which has been subsequently followed by the appearance of sarcoma. Nevertheless, Cahan *et alia* (1948) record a fatal chondrosarcoma which appeared seventeen years after the administration of 1 550 r for a bone cyst of the femur (male aged 24 years). The plurality of courses of X ray treatment may have some bearing upon sarcoma induction. Buschke and Cantrill (1949) state that they have no knowledge of any instance where sarcoma has followed a *single course* of X radiation. They draw an analogy between sarcoma initiation and the known carcinogenic effect of repeated sub-erythema doses of X-rays given over a prolonged period. Experimental work also, with various ionizing radiations, indicates the greater sarcogenic effect of *repeated* exposures.

Clinical Features. The most constant symptom is pain, which is progressive and persistent. Later a swelling may appear, but in several cases of sarcoma arising after the irradiation of normal bone, the swelling has preceded the pain. Related skin or soft tissue changes from former irradiation may be present, but are likely to be minimal with super voltage therapy. Usually the site of the suspected sarcoma and the longer latent period will serve clinically to differentiate it from a radionecrosis of bone.

Diagnosis. As with other skeletal lesions, this must be based upon full consideration

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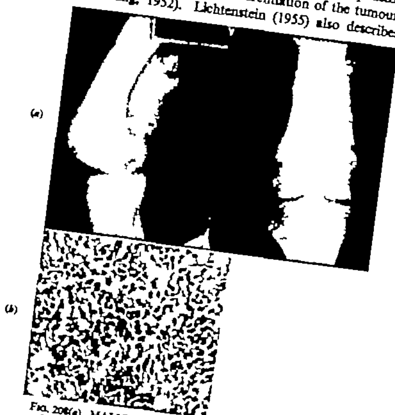


FIG. 208(a). MALIGNANT SYNOVIOMA. B.T.R./89. F aged 52. The radiograph reveals extensive flocculent calcification in the soft tissue tumour. There is considerable involvement of the medial femoral condyle. This is the picture seen five years after surgical removal of a malignant synovioma and stresses the treacherous nature of the tumour and the usual result following local excision.

FIG. 208(b). MALIGNANT SYNOVIOMA. (H. & E. × 120). B.T.R./640. F aged 63. The chosen field shows typical features of synovioma, viz., spheroidal cells of moderate size distributed through a dense collagenized stroma in which are many tissue clefts. In this, and in other tumours of the group, some parts showed a fibrosarcomatous appearance.

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There are certain similarities which occur throughout these several groups. These may not be constant, but are sufficiently frequent to be noteworthy

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Clinical Features. The most constant symptom is pain, which is progressive and persistent. Later a swelling may appear but in several cases of sarcoma arising *after the* irradiation of normal bone, the swelling has preceded the pain. Related skin or soft tissue changes from former irradiation may be present, but are likely to be minimal with supervoltage therapy. Usually the site of the suspected sarcoma and the longer latent period will serve clinically to differentiate it from a radionecrosis of bone

Diagnosis. As with other skeletal lesions, this must be based upon full consideration

of clinical, radiographic, and histological findings Before a case is accepted as a post irradiation sarcoma, the following criteria should be observed

(1) Full proof of the benign nature of the irradiated lesion.
(2) Appearance of the new growth within the irradiated area.
(3) A relatively long asymptomatic latent period.
(4) Final full proof of malignancy in the suspected tumour

Treatment. This is primarily a surgical problem (resection or amputation) The prognosis is, of course, that of the tumour allegedly induced by irradiation according to the tumour type grade, site, stage, age of patient, etc.

For the present, the only moral to be drawn from the accumulated clinical and experimental evidence points to the wisdom of adopting a cautious attitude in the application of radiotherapy to non malignant lesions of bone and related tissues, with care in avoiding immoderate dosage and repetitive treatment.

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CHAPTER XII

SURGERY OF THE HIP JOINT

E. N. WARDLE

Introduction

STABILITY is inherent in the structure of the hip joint and the limitation which this imposes upon a comprehensive range of movement is overcome by the multiplying advantage of a long leg lever cranked at the angle of the femoral neck and shaft. The opposite state of affairs is illustrated by the shoulder joint where there is little bony contact and a large range of movement is inherent in the structure stability being enforced by an envelope of powerful muscles. The design of the hip has its bearing on the clinical signs and pathology of conditions affecting the joint and must ever be kept in mind when formulating treatment.

The examination of a patient suspected of a lesion in the hip must pay particular attention to the following groups of clinical signs

(*a*) Those associated with the range of movement, whether there is limitation in all directions which usually signifies abnormality within the joint or in some directions only which tends to indicate changes in tissues outside the joint whether pain is present and whether or not there is muscle spasm.

(*b*) Those connected with deformity which may be due to structural malformation or destruction of bone on the one hand or to muscle spasm on the other or to a combination of both. Elevation of the greater trochanter and absence of the femoral head from the position marked by the line of the femoral artery crossing Poupart's ligament are good evidence of structural alteration. True shortening, measured from the anterior superior spine to the internal malleolus confirms this. Apparent shortening, measured from a central point on the trunk, such as the umbilicus, to the internal malleolus indicates an adduction deformity if it is greater than the real shortening and an abduction deformity when it is less these deformities are more often due to spasm than to structural change. Thomas's hip flexion test measures a flexion deformity which may be caused by muscular contracture or deformation of the joint, and calls attention to the mobility of the lumbar spine (Fig. 209). Practical shortening, the amount which must be added to the shoe to make a patient stand straight with lower limbs parallel and extended is the sum of all deformity present.

(*c*) Those concerning stability Trendelenburg's sign is an indication of instability and is based upon the fact that to stand on one leg necessitates active abduction of the hip taking the body weight, although this movement is made by tilting the pelvis on the femur Abduction of the weight bearing hip causes the opposite side of the pelvis to rise. The sign is thus said to be negative (Fig. 210) when the opposite side rises, and positive (Fig. 211) when the opposite side does not rise For example if the fulcrum is absent as in dislocation or the gluteal muscles are paralysed, then the sign will be truly positive and the instability obvious while a fixed adduction deformity or coxa vara will give a relatively positive sign and the instability is partly masked.

(*d*) *Gait* Typical disturbances are the "stiff hip" limp, the lurching walk of unilateral instability the waddling gait of bilateral instability and the "hurrying off one leg" limp of a painful hip Saunders, Inman and Eberhart (1953) have made an *extensive analysis* of human locomotion using the imaginative device of a biped with two rigid lower limbs



FIG. 209 Thomas's Hip flexion test

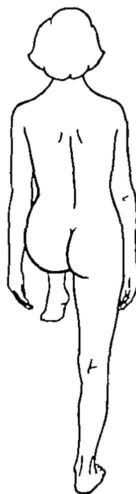


FIG. 210. TRENDELENBURG'S SIGN. Normal Hip. Negative sign opposite side of pelvis rises.

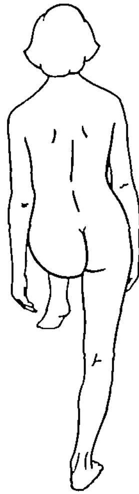


FIG. 211 TRENDELENBURG'S SIGN No fulcrum (e g. dislocation). Positive sign opposite side of pelvis falls.

firmly fixed to an equally rigid pelvis and spine. As joints are gradually introduced at the hips and knees it becomes apparent that the centre of gravity of the body makes a smaller rise and fall for each step and therefore the mechanical advantage becomes greater until it reaches the perfection of the normal human being in whom the maximum efficiency is obtained for the least expenditure of energy One of their diagrams is included here because it is the key to understanding pelvic tilt, pelvic rotation and elevation (Fig. 212)

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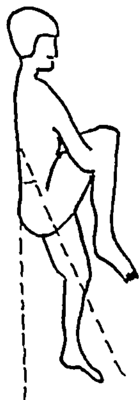


Fig. 209 Thomas's Hip flexion test.

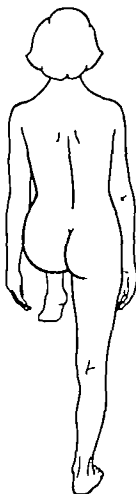


Fig. 210. TRENDELENBURG'S SIGN Normal Hip Negative sign: opposite side of pelvis rises.

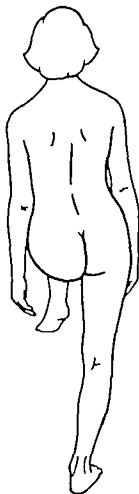


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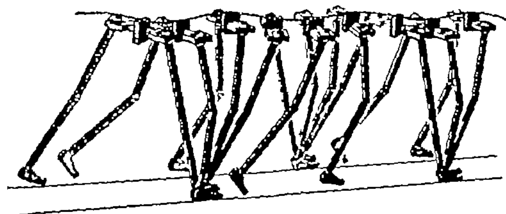


FIG. 212. *The Determinants of Normal Gait* This illustration sums up all the features of the hip joint movement in walking which are dealt with in detail by Saunders, Inman and Eberhart (1953)

Exposure of the Hip

Modern routes to the hip joint divide naturally into those passing in front of *tensor fasciæ femoris* and those which go behind that muscle.

Antero-Lateral. The skin incision is in the line of the iliac crest and extends downwards on the front of the thigh.

(*a*) The original Smith-Petersen (1936) approach marked an epoch in hip joint surgery because it reduced to a minimum shock from hæmorrhage and the cutting of muscle It gives wide access to the anterior and lateral aspects of the hip by the separation of muscles from one another and from bone along natural lines of cleavage. The interval between *tensor fasciæ femoris* and *sartorius* is opened in the thigh and also that between *gluteus minimus* and *rectus femoris* in the deeper layer The tensor and gluteal origins are then stripped from the superficial surface of the ilium with a rugine and the whole muscle mass turned outwards to expose the capsule of the hip. One of the disadvantages of this approach is the difficulty experienced in reattaching the gluteal muscles firmly to the iliac crest which may disturb the function of the hip after healing and produce a limp through weakness of the abductors.

(*b*) In the later modification by Smith-Petersen (1948), access to at least two thirds of the acetabular circumference and capsule of the hip for the purpose of arthroplasty is obtained by reflexion of the whole of the *rectus femoris* tendon downwards, and the stripping of the muscles from both the deep and superficial surfaces of the ilium.

Postero-Lateral. Several skin incisions can be used they are associated with the names of Kocher Brackett, Murphy and Gibson. Whichever skin incision is employed

the gluteal fascia is divided along the upper and outer edge of the *gluteus maximus* or the muscle itself is split in the length of its fibres, and the incision is extended through the fascia femoris downwards in the centre of the lateral aspect of the thigh This gives a rapid and bloodless exposure of the hip The greater trochanter may be removed carrying *gluteus medius minimus* and *pyriformis* with it or the muscle insertions can be cut from the bony process and sutured back on closure There is an approach to the hip which combines many of the advantages of both those just described and allows the surgeon access through whichever side of the tensor fascia femoris he chooses (Mas montoeil 1933) The skin incision is Z shaped commencing along the anterior part of the iliac crest, turning downwards and backwards from the anterior superior spine to the greater trochanter and turning again to continue down the middle of the outer aspect of the thigh. The flaps thus marked out are raised with the superficial fascia. The deep fascia is then incised from below upwards reaching the trochanter and then travelling towards the anterior superior spine. At choice the *tensor fasciæ* can be stripped from the iliac crest and retracted forwards while *gluteus medius* and *minimus* are retracted back wards or the *tensor fasciæ* can be split in the long axis of its fibres or the fascia can be incised in front of this muscle and it may then be detached from the iliac crest with the glutei in exactly the same manner as Smith-Petersen originally described. In this approach only one leash of major vessels needs to be divided that travelling from the anterior margin of gluteus medius to tensor fasciæ femoris and it will give access to the acetabulum, femoral head, neck and trochanters all in the compass of one skin incision.

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CONGENITAL DISLOCATION OF THE HIP

The etiology of congenital dislocation of the hip is not clear There is a strong suggestion that genetic factors are involved in some parts of Italy the condition is almost endemic in India, China and West Africa it is hardly ever reported. Recent work (Duraiswami 1952) indicates that abnormalities in maternal metabolism, by altering the intrauterine environment, may produce this and many other congenital deformities the fairly frequent association of congenital dislocation with spina bifida and club feet is not without significance in this respect. Abnormal position of the foetus in utero and lack of amniotic fluid have been put forward as causative factors but this view is not generally accepted. Most authorities are agreed that the reposition of a congenitally dislocated femoral head to normal position stimulates an otherwise dysplastic acetabulum to growth but correct position of the head is no guarantee that it itself will not undergo degenerative change and this may occur quite early in life.

Pathology

In the absence of a femoral head the acetabulum becomes shallow sometimes triangular and filled with indeterminate fibrous tissue and its roof is defective without an

acetabulum the femoral head does *not develop its normal spherical shape* and ossifies slowly The capsule of the hip is voluminous, adherent to the ilium and sometimes constricted to an "hour-glass" shape with the femoral head in one compartment and the acetabulum in the other The *cotyloid ligament* may remain, although in a distorted and attenuated form and a false acetabulum may form above it or it may be spread on to the dorsum illi as if pushed by the displaced head. The relation of this structure to the femoral head probably distinguishes congenital dislocation from congenital subluxation (Nove-Josserand, 1925) (Fig. 222) although some authorities deny that this distinction exists or that it is of any importance. The *limbus*, originally described by the French workers and to which attention has again been directed by Somerville (1953), is also the subject of discussion whether it is an infolding of the labrum which fills the acetabulum with debris as mentioned earlier or whether it is a double fold of capsular tissue trapped between the femoral head and ilium when the leg is abducted Not infrequently the femoral head undergoes changes which produce an appearance reminiscent of Perthes disease even after successful reduction.

Arthrography The radiographic technique of delineating the cavity of a joint offers the possibility of giving more accurate information concerning the disposition of the capsule and the cotyloid ligament. Whether an opaque medium or simply air be injected into the joint, the procedure is not without risk and in very small children and babies the risk may be considerable It has been pointed out (Murray 1950) that the procedure is always associated with an eosinophilia. In those children where reduction is straight forward the arthrogram is unnecessary in those where reduction is difficult, open operation is necessary and gives a far more accurate view than that given by the arthrogram. Most surgeons feel that the procedure is not worth the risk

Diagnosis and Treatment

It is convenient to consider *diagnosis and treatment* together in certain age groups

Birth to 12 months. (This was the period chosen by Fairbank for his review in 1939)

In the newborn, great importance attaches to the observance of an increase in the number of skin folds on the inner surface of the thigh and broadening of the perineum. *These are the earliest clinical signs and often the only ones to* be detected in a baby At six months a child may be sufficiently grown for "telescoping" to be elicited while at twelve months it is possible to detect the absence of the head of the femur from the acetabulum by pressing firmly under Poupart's ligament at the pulsation of the *femoral artery* and to observe any prominence of the greater trochanter laterally In unilateral dislocation the limb may be seen to be short. Radiographically any "stand-off" of the upper end of the femur from the pelvis, or elevation of it in relation to the acetabulum should arouse suspicion and the absence of an ossific centre in the capital epiphysis, or diminution of its size, confirms the diagnosis (Figs. 213 and 214).

It is beyond doubt that a congenital dislocation of the hip recognised in an infant, will be reduced by simple abduction (Fig. 215 same child as Fig. 213). This position can be maintained by a divaricator of one form or another (Putti, 1935 and Forrester Brown, 1935) until such time as the child is large enough for a plaster cast. The earlier reduction is made, the less likely is redislocation to occur or the necessity for prolonged fixation.

One to Three Years. The clinical signs are now obvious. The displaced femoral head can be felt on the dorsum ilii, telescoping is easily produced and once the child attempts

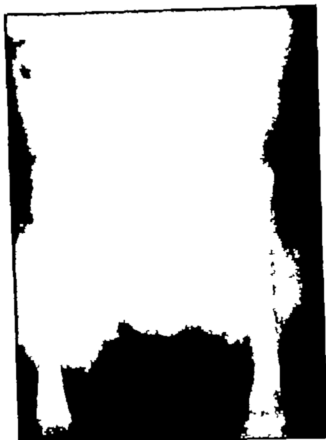


FIG. 213 Radiograph of a child aged 8 weeks to show "stand off" and elevation of the upper end of the femur on the left side.



FIG. 214 Radiograph illustrating the diminution in size in the ossific centre of the capital epiphysis

acetabulum the femoral head does not develop its normal spherical shape and ossifies slowly The capsule of the hip is voluminous, adherent to the ilium and sometimes constricted to an "hour-glass" shape with the femoral head in one compartment and the acetabulum in the other The *cotyloid ligament* may remain, although in a distorted and attenuated form and a false acetabulum may form above it or it may be spread on to the dorsum ilii as if pushed by the displaced head The relation of this structure to the femoral head probably distinguishes congenital dislocation from congenital subluxation (Nove Josserand, 1925) (Fig. 222) although some authorities deny that this distinction exists or that it is of any importance. The *limbus* originally described by the French workers and to which attention has again been directed by Somerville (1953), is also the subject of discussion whether it is an infolding of the labrum which fills the acetabulum with debris as mentioned earlier or whether it is a double fold of capsular tissue trapped between the femoral head and ilium when the leg is abducted. Not infrequently the femoral head undergoes changes which produce an appearance reminiscent of Perthes disease even after successful reduction.

Arthrography The radiographic technique of delineating the cavity of a joint offers the possibility of giving more accurate information concerning the disposition of the capsule and the cotyloid ligament. Whether an opaque medium or simply air be injected into the joint, the procedure is not without risk and in very small children and babies the risk may be considerable. It has been pointed out (Murray 1950) that the procedure is always associated with an eosinophilia. In those children where reduction is straightforward the arthrogram is unnecessary in those where reduction is difficult, open operation is necessary and gives a far more accurate view than that given by the arthrogram. Most surgeons feel that the procedure is not worth the risk

Diagnosis and Treatment

It is convenient to consider *diagnosis and treatment* together in certain age groups

Birth to 12 months. (This was the period chosen by Fairbank for his review in 1939)

In the newborn, great importance attaches to the observance of an increase in the number of skin folds on the inner surface of the thigh and broadening of the perineum. These are the earliest clinical signs and often the only ones to be detected in a baby At six months a child may be sufficiently grown for "telescoping" to be elicited while at twelve months it is possible to detect the absence of the head of the femur from the acetabulum by pressing firmly under Poupart s ligament at the pulsation of the femoral artery and to observe any prominence of the greater trochanter laterally In unilateral dislocation the limb may be seen to be short. Radiographically any "stand-off" of the upper end of the femur from the pelvis, or elevation of it in relation to the acetabulum should arouse suspicion and the absence of an ossific centre in the capital epiphysis, or diminution of its size, confirms the diagnosis (Figs. 213 and 214).

It is beyond doubt that a congenital dislocation of the hip recognised in an infant, will be reduced by simple abduction (Fig. 215 same child as Fig. 213). This position can be maintained by a divaricator of one form or another (Putti, 1935 and Forrester Brown, 1935) until such time as the child is large enough for a plaster cast. The earlier reduction is made, the less likely is redislocation to occur or the necessity for prolonged fixation.

One to Three Years. The clinical signs are now obvious. The displaced femoral head can be felt on the dorsum ilii, telescoping is easily produced and once the child attempts



FIG. 213 Radiograph of a child aged 8 weeks to show "stand off" and elevation of the upper end of the femur on the left side.



FIG. 214 Radiograph illustrating the diminution in size in the ossific centre of the capital epiphysis



FIG. 215. Radiograph to illustrate reduction of congenital deformity of the left hip by simple abduction. (The same child as Figure 213 8 months later.)



FIG. 216. Radiograph to illustrate the acetabular index in a normal hip and a congenital dislocation.

to walk a limp is seen. From two years onwards the child is large enough for the legs to be measured and the hollow in the groin is easily felt Radiographs now show a deficient and sloping acetabular roof as well as obvious displacement of the upper end of the femur and the capital epiphysis remains small. Horizontal and vertical lines drawn through the acetabulum as demonstrated in the figure, serve to measure the amount of displacement (Fig. 216).

Diminishing elasticity and increasing upward displacement of the femoral head prevent easy replacement by abduction at this stage but manipulation under anæsthesia is frequently successful. The original Lorenz (1896) "bloodless" reduction used an amount of force which is now deprecated but the basis of the manœuvre remains the same. The thigh is flexed upon the abdomen to carry the femoral head downward the limb is then abducted to approximate the femoral head to the acetabulum with one hand under the buttock and the other grasping the knee to rotate the leg in whichever direction is necessary the head of the femur is then lifted into the acetabulum. The need for tenotomy of the adductor origins is a debatable question some authorities argue that tightness in these muscles prevents that abduction which is necessary for reduction whilst others use this muscular rigidity as an aid in levering the head into position. The reduced hip is held in a plaster spica some surgeons include the normal leg to the knee, others content themselves with immobilization of the whole of the abnormal one. The term "frog position" is sometimes used to describe this position, but it is misleading rarely will the thigh and the calf both be in the coronal plane with the hip reduced, some rotation is nearly always necessary Reduction is confirmed clinically by palpating the groin under the edge of the plaster and feeling the femoral head properly centred deeply in the acetabular hollow (Fig. 217) After three months the plaster is removed and the leg



FIG 217 Complete reduction of a congenital dislocation of the left hip.

cautiously brought into less abduction and rotation If the femoral head remains in the acetabulum a new plaster is applied in this position and the process repeated at three monthly intervals until the limb is in weight bearing alignment. A successful result is illustrated (Fig. 218). If the hip cannot be reduced at the first manipulation it should be placed on traction for two or three weeks This is most efficiently applied with the legs in abduction on a Jones double hip splint a method which has been in use in Liverpool from the time of Sir Robert Jones and which figures prominently in the more recent work of Scott at Oxford where this method is used *ab initio* Another attempt at manipulative



FIG. 218 Radiograph to illustrate a successful result in the treatment of congenital dislocation of the hip. (The same patient as Figure 216, seven years later)

reduction is then made. Three failures demand open reduction. Similarly if the hip redislocates as the leg is brought down exploration is indicated (Fig. 219 (*a*)). The factors tending to prevent manipulative reduction are a large fold of capsule interposed between the femoral head and the acetabulum, the capsule adherent to the ilium and "hour-glass" constriction, a large ligamentum teres and disparity in size between the head and the acetabulum. The first three present no great difficulty and their removal produces most of the good results claimed for reposition by open operation. The last is a serious obstacle it may sometimes be overcome by clearing the acetabulum of articular cartilage to enlarge the cavity as suggested by Colonna (1932) Before this is done it is necessary to have a preliminary period of traction, to bring the femoral head as near as possible to the level of the acetabulum. The hip is then exposed, the capsular constriction is divided circumferentially and the acetabulum explored. All fibrous material and redundant capsule is removed and the cavity is enlarged and deepened by the removal of the remnants of articular cartilage and of bone if necessary until the femoral

head fits it comfortably The capsule is then resutured over the femoral head. Closure is followed by further fixation and this must be continued until the healing of soft tissues is sound enough to resist any tendency to redislocation this may take three months There is risk of a stiff hip.

Three to Six Years. The clinical signs are now very obvious The child has a marked lurching gait, real shortening of the leg is considerable, there is an adduction deformity

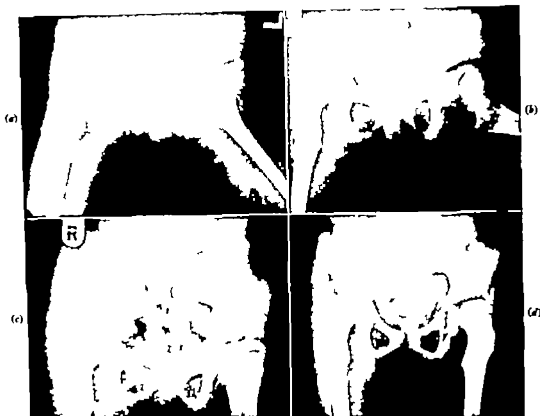


FIG. 219( ). Redislocation. Note the sloping acetabular roof and the capital epiphysis projecting beyond the bony cover (b) The same patient after open reduction and reconstruction of the acetabular roof. (c) The same patient one year later (d) The same patient after a further two years.

at the hip and the lumbar lordosis is exaggerated. Radiographs often show a false acetabulum in addition to the features already illustrated. Manipulative reduction is rarely possible. Open reduction is rendered increasingly difficult by the deformity even after a preliminary period of traction but it must be undertaken. It is particularly in this age group that Colonna has used his procedure An equally difficult situation is produced by the redislocation of hips successfully reduced earlier in life. The conditions which predispose to the latter are not easily defined. Lack of development of the lateral lip of the acetabulum and malposition or absence of the superior and lateral portion of the cotyloid ligament are certainly concerned Increase of the angle of anteversion is held to be a potent cause by some authorities but in company with many others the present

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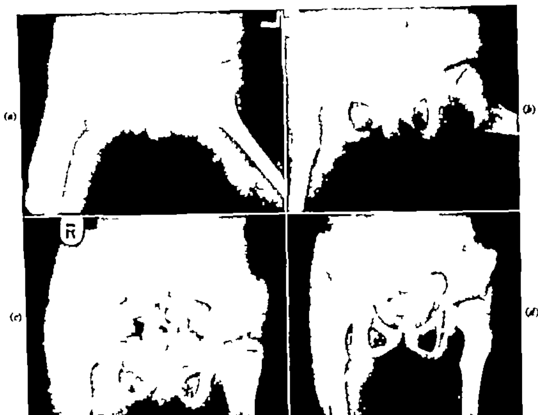
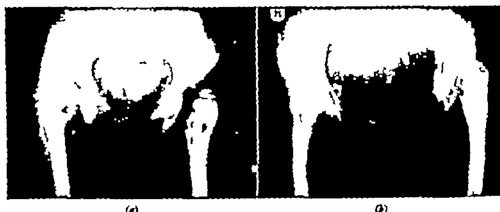


FIG. 219(*a*). Redislocation. Note the sloping acetabular roof and the capital epiphysis projecting *beyond the bony cover.* (*b*) *The same patient after open reduction and reconstruction of the acetabular roof.* (*c*) The same patient one year later. (*d*) The same patient after a further two years.

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writer regards it as a radiological illusion but increase of the normal angle of the femoral head with the shaft, coxa valga, would certainly seem to lead to displacement of the femoral head as the leg is brought into weight bearing position. As already pointed out reduction at an early stage with the stimulus of a head in proper position, will often cause the lateral lip of the acetabulum to grow but if at open reduction the cotyloid ligament is seen to be absent or displaced a large hood of bone from the corresponding area of the ilium including the lateral margin of the acetabulum should be turned down over the femoral head and the gap between it and the remainder of the ilium filled with grafts (Fig. 219 (*b*) (*c*) and (*d*))

This is really the "shelf" operation, originally designed to stabilize unreduced dislocations in late childhood and adolescence, but now abandoned for that purpose



(*a*) (*b*)

Fig. 220(*a*). Bilateral congenital dislocation of the hip remaining unreduced in a child aged three years. (*b*) The same patient 15 years after the original manipulation. Both hips were finally reduced by open operation and later corrective intertrochanteric osteotomies were performed Note that both hips are completely stiff although the poorly formed heads lie in natural relation to the ill defined acetabula.

Rotation osteotomy for the correction of anteversion or valgus deformities raises certain difficulties because some form of internal fixation is required to maintain the position of the upper fragment while the lower one is orientated upon it either a pin which is left projecting through the plaster spica or a nail plate of special design must be used. Stiff hips may easily result from long continued fixation following one or more open operations even though the femoral head is in natural position (Fig. 220 (*a*) and (*b*)).

Over Six Years. All the clinical signs previously mentioned are apparent. The chief radiological feature is a false acetabulum Manipulative reduction is impossible. Open reduction may still be possible in these older children but the amount of force necessary to overcome the shortening is dangerous and a stiff hip is the usual result. Arthroplasty for unreduced congenital dislocation in adolescents is as unsuccessful as it is for osteoarthritis in later life. The indications for interference in an adult are pain and limp. At *this time a "bifurcation" osteotomy is at present the most successful procedure known* (Fig. 221). There are two types of osteotomy (*a*) the Lorenz which is intertrochanteric in position and (*b*) the Schanz osteotomy which is subtrochanteric. In both the distal portion of the femur is abducted and the proximal portion takes some support directly



FIG. 221 Radiograph to illustrate the result of displacement osteotomy carried out in an adult with untreated congenital dislocation of the [illegible]



FIG. 222 Radiograph showing an adult patient with an untreated [illegible] of the hip on the right side and congenital subluxation on the [illegible]

on the lateral pelvic wall. Very careful judgement is required for these patients. A yo adult with one stiff hip fixed in good position is not greatly disabled. The plight of a person with two stiff hips needs to be weighed against the known result of no treatm at all (Fig. 222) For it is not uncommon to see such untreated individuals leading a f free and active life until the age of 40 If at that age their hips do become painful t displacement osteotomy relieves the symptoms.

Prognosis

It is accepted that the earlier a congenital dislocation of the hip is recognized reduced, the more certain is a successful outcome—a stable painless hip with a g range of movement and legs of equal length. It is also true that once a hip is reduce the leg is kept fixed long enough in the position which corresponds to replacement of femoral head, it will not redislocate but the price may be a stiff hip with consider deformity which, however can be corrected by a simple osteotomy at a later date. Th is also no doubt that many patients with two unreduced congenital hips live a nor life of reasonable activity and without undue pain up to middle age but at the cost of unsightly gait and considerable deformity All these facts must be given due weigh assessing the individual patient. The parents of a new born child in whom a congen dislocation of the hip has been recognized can be told that there is an 80 per cent cha of reduction by simple abduction and that suitable retention for a period of two ye carries about the same chance of a normal hip. In the case of a child untreated until year old the possibility of closed reduction is reduced to about 60 per cent and ther less than this likelihood of a good functional hip failure of manipulation demands open reduction with even less chance of good function and the prospects of retent for a considerably longer period At the age of six years without any previous treatm the possibility of closed reduction has almost disappeared and operative repositio only likely to produce a hip with limited movement and some instability at the b The stage is reached at eight or nine years where reduction is hardly worth while and best advice is to leave the hips alone, if the condition is bilateral, and to inform parents that arthrodesis offers a possible alternative in the unilateral case. Whe congenital dislocation of the hip persistently redislocates it can be pointed out that treatment possible is a reconstructive or corrective operation, which is not likely to g normal function. Alternatively retention in a plaster spica over a long period, follov by a corrective osteotomy of a stiff hip several years later both of which deprive child of normal activity during its growing years The adult with an unreduced congе tal dislocation can be told that a displacement osteotomy will relieve pain and stabi the hip without lessening the range of movement present and that the operation can successfully carried out on two hips in the same patient.

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SLIPPED UPPER FEMORAL EPIPHYSIS

Adolescent Coxa Vara

is not a very common lesion and it has aroused curiosity and interest since it was
cribed because no satisfactory etiology has been discovered and no one method
nent has proved generally successful (Kocher 1893 Kirmisson, 1902 Elmslie,
Key 1926)

s usually been held that endocrine imbalance plays some part in its production
ry has always been high in the list of possible causes. While it remains true, on
hand, that individuals with gross signs of pituitary disorder may displace their
epiphysis even when fixed in recumbency and, on the other hand, that violent
nay produce a true fracture separation at the upper femoral epiphyseal line,
eless a careful study of many case histories from a variety of sources shows that
ority of these patients are normal adolescents. They have usually complained of
ng hip or knee for some months and then a comparatively slight injury has
in deformity and stiffness. In recent years a precise contribution to etiology has
ade by Harris of Toronto (1950) He has shown, in laboratory animals, that the
of force necessary to displace the upper femoral epiphysis is greater when an
of sex hormone is circulating and much less when there is a preponderance of
hormone. He has also correlated histological changes in the epiphyseal cartilage
se hormonal variations and has shown that cleavage usually occurs at the junction
lage and metaphysis It is probably the case that the conjunction of a temporary
derance of growth hormone with minor trauma starts the process and the resulting
ance of mechanical equilibrium sets up a vicious circle of increasing deformity

gnosis. Slipped epiphysis may be unilateral or bilateral and has been recorded in
as young as 8 years and in adolescents as old as 17 Once it has occurred the
signs are plain the affected leg is shortened and there is an adduction eversion
ity at the hip with painful limitation of movement. In the early stages there are no
signs and the prompt diagnosis which is so essential depends entirely on radiologi
lings. These are alterations in contour of the upper and lower borders of the
l head and neck (Fig. 223) and patchy areas of rarefaction in the metaphysis (Fig.
he so-called "preslip stage" Certainly no patient between the ages of 10 and 16
mplaints of persistent pain in the hip or knee should be discharged from observa
ntil serial radiographs up to 12 months have shown that these changes are *not*
t. The evolution of the condition is also most easily appreciated in radiographs and
s purpose true lateral views of the hip are necessary A buttress of ossifying tissue
s at the inferior extremity of the epiphyseal line and the inferior border of the neck
femur (Fig. 226). Very often displacement is more apparent in the lateral projection
e anterior buckling at the epiphyseal line gives the appearance of displacement of
nur upon the epiphysis (Fig. 227) The degree of slip is recorded as one-quarter
lf three-quarters or whole displacement in the antero posterior and lateral



FIG. 223 To illustrate the early radiological sign of alteration in contour of the upper margin of the femoral neck and head. Note also the exclusion *of the diaphysial portion of the caput* from the acetabulum inferiorly



FIG. 224 To illustrate the early radiological sign of rarefaction in the metaphysis of the femoral neck

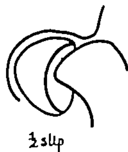


Fig. 223 To illustrate the early radiological sign of alteration in contour of the upper margin of the femoral neck and head. Note also the exclusion of the diaphyseal portion of the caput from the acetabulum inferiorly



FIG 224 To illustrate the early radiological sign of rarefaction in the metaphysis of the femoral neck.







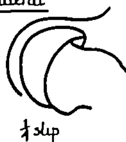






FIG. 225 Line drawings to show the "degree of slip"



FIG. 226 Radiograph to illustrate the buttress of ossifying tissue.

views (Fig. 225). Investigation of the output of urinary ketosteroids and statistics of height, weight sex and onset of puberty have not yielded information of use in diagnosi

Continued observation of a series of patients into late adolescent and adult li reveals three clinical types

(a) Those in whom, whatever the degree of displacement and whether treated or nc



FIG. 227 The appearance as of displacement of the femoral diaphysis upon the epiphysis.

a good range of active movement remains in the hip however deformed it may (Fig. 226).

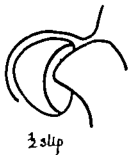
(b) Those in whom the hip fuses. Early diminution of joint space in the radiograp is an important indication of this (Fig. 228).

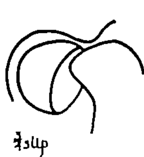
(c) The true fracture separation at the epiphyseal line which behaves in exactly t same way as similar lesions in any other part of the body

The recognition of these types has an important bearing on treatment.

Pathology Tissue removed from the epiphyseal area shows disorganization of t growth of the cartilage. The cells are irregularly disposed in contrast to their usu arrangement in columns and the epiphysis fuses at an earlier date than normal for t







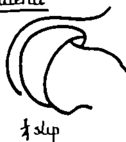






Fig. 225 Line drawings to show the degree of slip.



Fig. 226 Radiograph to illustrate the buttress of ossifying tissue.

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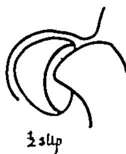
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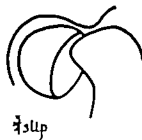
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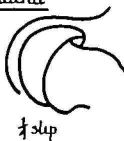






FIG. 225 Line drawings to show the degree of slip.

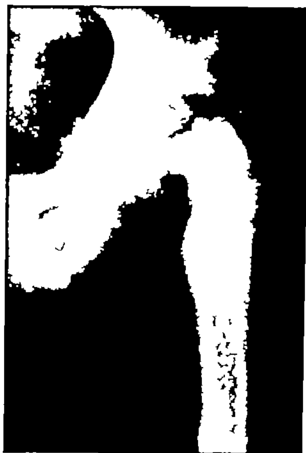


FIG. 226. Radiograph to illustrate the buttress of ossifying tissue.

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Continued observation of a series of patients into late adolescent and adult life reveals three clinical types

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FIG. 227 The appearance as of displacement of the femoral diaphysis upon the epiphysis.

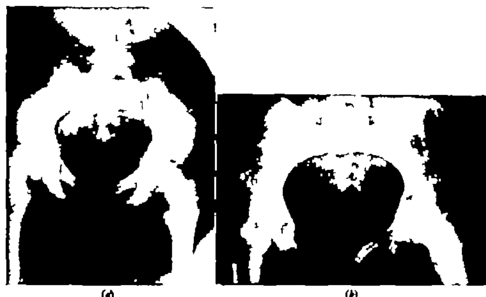
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(*a*) (*b*)

FIG. 228 Both hips of girl aged 12 years in 1938. (*a*) Gross displacement of the R capital epiphysis. The displacement present on the left side occurred while the patient was immobilized on a double frame. Note the diminished "joint space" on both sides (*b*) Fusion of both hips in 1940.



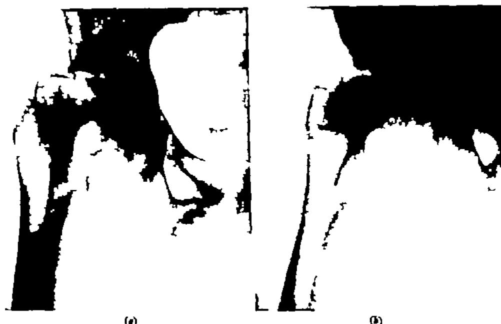
FIG. 229 Radiograph of both hips of girl aged 15 years in 1945 3 years previously a minimal slip of right upper femoral epiphysis was immobilized for 6 months on frame followed by a plaster spica

particular individual The ossific centre of the femoral head seems gradually to undergo the changes associated with aseptic necrosis and these are more marked the greater the degree of uncorrected displacement.

Treatment Unless the greatest care is taken and careful judgement is exercised for each patient Key's (1926) paradox will be found still true "the results in untreated patients are better than the results of treatment." There are certain facts upon which such judgement can be based

(1) If the epiphysis is fixed to the metaphysis and kept so until the epiphyseal line closes, no further displacement will occur (Fig. 229)

(2) When displacement has occurred a certain proportion of these lesions will be reduced by traction (Wardle, 1933) (Fig 230)



(*a*) (*b*)

Fig. 230(*a*) The right hip of a boy aged 12 4/58. (*b*) The same hip following two weeks fixed traction on a Thomas frame.

(3) If diminution of joint spacing is seen in early radiographs the hip will fuse (compare Fig. 228).

(4) The simple "fracture separation" reduces easily by manipulation under anæsthesia but this is a dangerous procedure for any "ordinary" slipped epiphysis

(5) The epiphysis as it grows possesses a great tendency to remodel the head and neck of the femur therefore a displacement of up to one third diameter can be accepted (compare Fig. 226)

A child of 12 with a unilateral lesion recognized at the "pre-slip" stage requires that the epiphysis be fixed until the epiphyseal line closes. The period will vary with sex and genotype but some idea of the probable date of skeletal maturity can be obtained from radiographs of the pelvis and long bones and in any case the period of fixation will be some years. The desired end can be obtained by immobilization in a plaster spica or on a

frame splint for 3 months, followed by a walking caliper until the epiphyseal line closes. This is bad for the patient as a whole. Internal fixation as first described by Waldenstrohm (1936) is clearly the correct treatment under these circumstances and produces excellent results (Fig. 231) Just as clearly it is wrong treatment when the patient is aged

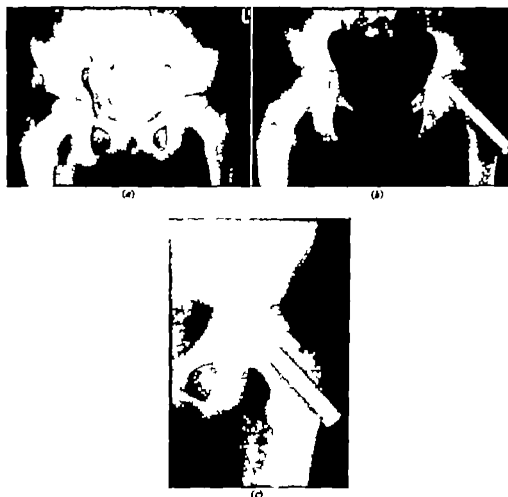


FIG 231 Three radiographs to show the result of a simple nailing in slipped upper femoral epiphysis in a boy aged 12. (*a*) The original lesion 2/55 (*b*) The epiphysis sealed 5/55 (*c*) The result 2/56. Note that the epiphysis has "grown away" from the end of the nail which has since been removed. The hip now has normal function.

16 It is also acceptable treatment with displacement of up to one third diameter but not beyond this point.

When a patient is seen with displacement already present, even gross displacement, traction should be applied for three or four weeks. This is best carried out on a double hip splint with the leg pieces parallel and the groin strap on the side of the lesion but it can also be achieved on a Thomas bed knee splint or by a weight and pulley In an appreciable number of instances, reduction will occur quite suddenly (Fig. 230) within a

period of three weeks and the necessary fixation until the epiphyseal line has closed can be determined on the lines laid down in the preceding paragraph

Traction should not be continued for longer than 4 weeks and when displacement of more than one-third degree persists it should be corrected. Cervical wedge osteotomy (Badgley *et al* 1948) is the method but this operation demands extreme care and meticulous selection of patients It should never be carried out without a preliminary period of traction but must not be delayed until the time when the bone of the femoral head has become dense. Wide exposure of the hip is necessary and the wedge of bone should be removed, base upwards, without encroaching on the epiphyseal line. Internal fixation is essential and the nail must penetrate well into the femoral head. The patient must be kept in bed for 3 months following the operation (Figs. 232 and 233) Within these limits excellent results can be obtained. As an alternative to the use of the Smith Petersen nail for internal fixation, some surgeons use three or four Austin Moore pins. It is claimed that these thin appliances are mechanically efficient and less liable to produce damage to the vascular supply of the bone.

If at any time during treatment, diminution of joint spacing appears in the serial radiographs of the affected hip, all active measures should be abandoned. The hip is allowed to fuse and deformity corrected by a simple osteotomy later (Fig 234) or if the lesion is bilateral some form of arthroplasty may be attempted

A simple fracture separation at the upper femoral epiphysis can usually be recognized from the history of violent trauma, without prodromal symptoms, and a radiograph showing the small spicule of bone detached from the metaphysis which is the hallmark of these lesions. The correct treatment is manipulative reduction under anæsthesia. Manipulation is contra-indicated in all other patients because of the risk of precipitating a stiff hip.

Prognosis. It is unwise to offer an opinion on the future prospects of a patient with a slipped upper femoral epiphysis until observation has been extended to three months at least. While it is true to say that the earlier the lesion is detected the more likely is full function to be obtained, particularly if displacement is prevented or corrected, it is also true that at present there is no means of knowing which of these hips will proceed to fusion. Once it has been determined that movement will remain in the joint, proper treatment will always produce a good functional result and due weight can be given to the fact that there is a tremendous potentiality for remodelling of the head and neck of the femur to occur

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PERTHES DISEASE

This condition is regarded as one of the manifestations of osteochondritis. It is important because it can be confused at its onset with tuberculosis of the hip in young



(*a*) (*b*)

FIG. 232. A series of radiographs to demonstrate treatment by cervical wedge osteotomy and nailing in a girl aged 12 in 1952. (*a*) The original lesion of the *left* hip. (*b*) The condition 9 months later 11/52.

left *right*

FIG. 232(*c*). Both hips in 9/53. Note change in contour of the *right* femoral neck.

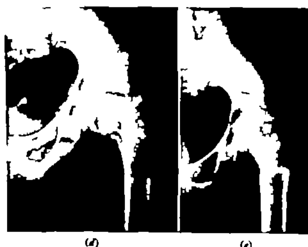


FIG. 232(*d*). The patient did not return to hospital until 4/56. Note the lesion in the right hip. Both hips had good function, the patient had no pain and the legs were of equal length.



(*a*) (*b*) (*c*)

FIG. 233 A series of radiographs to show the disaster of wrong application of principles of treatment. (*a*) The original lesion in a boy aged 13 in 1947 (*b*) Correction by open reduction and external fixation. (*c*) An attempt at cervical wedge osteotomy and nailing in 1949 when the bone was so dense that the operation had to be abandoned on account of shock.



(*d*) (*e*)

FIG. 233(*d*). The hip in 1950. ( ) The hip in 1956 after the consolidation of a corrective subtrochanteric osteotomy 2½ of real shortening.

(a) (b)

(c) (d)

FIG. 234 To illustrate the management of the inevitable stiff hip. Patient aged 13 years in 1945 (a) The slipped upper femoral epiphysis. (b) Diminution of joint spacing and no reduction by traction. (c) Fusion of the hip (d) Increasing adduction deformity



(e) (f)

FIG. 234(e) Correction by subtrochanteric osteotomy 1947 (f) The condition in 1956.

children and because it is thought to be one of the forerunners of the chronic osteoarthritis of the hip which occurs early in adult life

It can appear at any time between 2 and 15 years of age and may be unilateral or bilateral Trauma, infection and genetic abnormality have all in turn been held responsible Trauma because similar lesions are observed ipsilaterally in reduced congenital dislocations Genetic factors because the same changes occur contralaterally to a congenital dislocation whether reduced or not Infection because some of the patients are febrile and show muscle spasm. Jones and Lovett (1923) remarked that much had been written but little determined since Legg described the condition in 1910 The same can be said today However there is no doubt that certain anatomical factors render the femoral head peculiarly vulnerable just as much in childhood when it is a mass of cartilage in adolescence when it is precariously anchored by a narrowing zone of epiphyseal cartilage and in old age when it adjoins the softening femoral neck. The position of the expanded caput isolated from the femoral shaft by the narrow neck in what is a major weight bearing joint makes it certain that any abnormal force, traumatic, muscular or manipulative applied to the leg will be magnified by the time it reaches the hip. The arrangement of the nutrient vessels, which enter the bone by way of plicæ in the synovial membrane and capsule, renders them easily torn In addition there is the questionable blood supply through the ligamentum teres and the possible effect of its disruption, so that although direct evidence of trauma as a cause is lacking, it can be said that circumstances are favourable for this to produce a maximal effect and to enhance any hereditary tendency to abnormality which may be present. The exact cause remains unknown.

Clinical Signs. These range from an intermittent limp to complete limitation of movement at the hip joint the comparatively acute cases simulate tuberculosis—(pseudocoxalgia). Whenever a child complains of aching in the hip or the knee and the mother thinks she has noticed a limp, suspicion should be aroused. One normal radiograph does not rule out Perthes disease. The child should be examined at intervals and the radiographs repeated.

Radiological Appearances. The diagnosis, particularly the distinction from tubercle, is based upon the following signs. The earliest is widening of the "joint space," i e. the interval between the bony shadows of the acetabulum and femoral head. It is followed by condensation, diminution in height and fragmentation of the ossific nucleus. The neck of the femur appears broadened and there are cystic changes in the metaphysis (Fig. 235). Serial radiographs demonstrate the natural tendency to heal which finally distinguishes Perthes disease from tuberculosis and they show that the epiphysis of the femoral head usually is transformed into a flattened "mushroom" or else into a "cap" much broader than normal (Fig. 236) but may become radiologically normal (Fig. 237). Eyre Brook (1936) has described the ratio of height to breadth of the epiphysis as a radiographic index of deformity

Pathology Jackson Burrows (1941) described the thickening of the articular cartilage destruction of bone trabeculæ, and replacement by invasion of chondroid and osteoid tissue. He pointed out the difference between these changes, which are called osteochondritis, and avascular necrosis where the trabeculæ remain intact for a long time. Many workers have investigated Perthes disease but none has produced a completely satisfactory explanation of its nature



(*a*) (*b*)

FIG. 235 X-ray photographs of the hips of a boy (*a*) 3/55 illustrating widening of the joint space, complete condensation of the epiphyses of the head of the femur and an area of rarefaction in the metaphysis. (*b*) 8/55 To illustrate fragmentation of the capital epiphysis and marked increase of the joint space.

(*a*) (*b*)

(*d*) ( )

FIG 236. X-ray photographs of the hips of boy illustrating the healing of Perthes Disease with the flattened "mushroom type of femoral head. (*a*) 12/48. (*b*) 3/50. (*c*) 5/52. (*d*) 5/56.

Treatment. It seems reasonable, in view of the known tendency of Perthes disease to heal, to place the patient in bed with traction on the limb of the affected side and to allow free movement in order to preserve the spherical contour of the femoral head as far as possible at the same time recumbency prevents any compression of the soft bone and cartilage. Many workers however have maintained that this is quite unnecessary and that it makes no difference at all to the final clinical results the children might just as

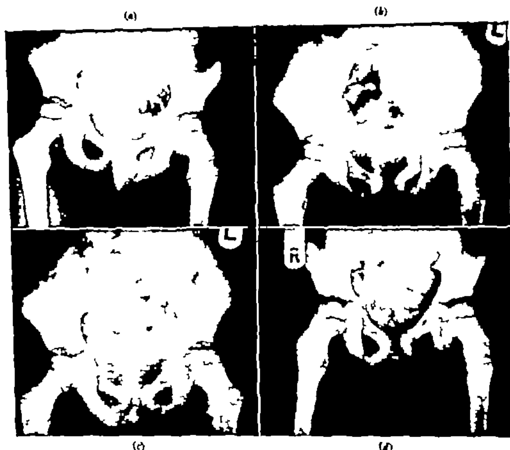


FIG. 237 X-ray photographs of the hips of a boy to illustrate the possibility of a radiologically normal result in Perthes Disease. (a) 10/52. (b) 4/53. (c) 10/53 (d) 1/55.

well be placed in weight relieving calipers from the time when the changes in the hip joint are recognized. Eyre Brook (1936) reached the conclusion that a preliminary period of weight traction in recumbency did produce better results in patients who were under 7 when the abnormality was recognized in its early stages. He maintained that this treatment gave the possibility of complete restoration to normal in a young patient although he agreed that recumbency made no difference to the clinical or radiological results in a patient over 7 at the beginning of treatment, or in whom the changes were well advanced before they were recognized. When the absence of clinical signs and the appearance of radiological regeneration indicates that healing is beyond doubt, the child is fitted with a caliper splint, which is continued until no further reformation of bone occurs. That this



(*a*) (*b*)

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(*a*) (*b*)

(*d*) (*c*)

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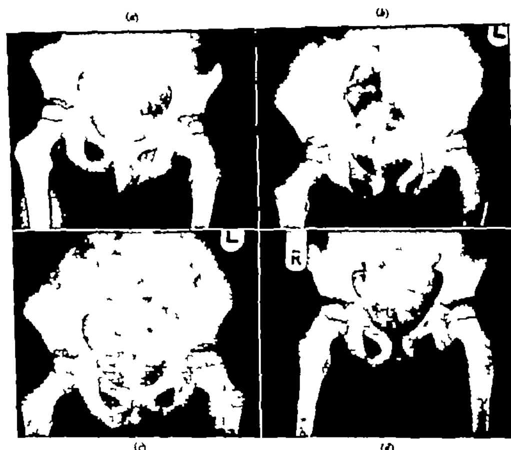


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(d) (c)

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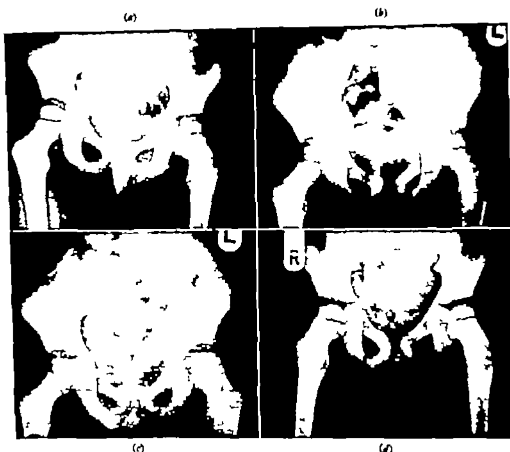


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can produce a normal hip is shown by Fig. 237 and it certainly gives the joint its best chance in most patients

Prognosis. It can be said with certainty that the hip will heal and a good functional result follow two years should be allowed for this The patients with poor regeneration may have a limp. There is no certain way of telling at the onset whether a given hip will reconstitute completely although a quick reappearance of normal bone texture after the original destruction is of good omen. The sooner treatment is commenced, the better the result. It is probably true that most patients who have Perthes disease in childhood develop chronic osteoarthritis in early adult life.

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PARALYTIC DISLOCATION OF THE HIP

This condition is usually encountered in long standing poliomyelitis and cerebral spastic paralysis but it may occasionally be observed in paraplegia from other causes as, for example, tuberculosis or fracture-dislocation of the spine

The clinical signs are commonly masked because the patient is unable to walk and the lower limbs are distorted before the hip is displaced so that routine radiographs usually give the first indication that the femoral head is leaving the acetabulum (Figs. 238 and 239).

The mechanics of this dislocation are not properly understood but it is not without significance that the subluxation is in the same direction, upwards and outwards, whether the paralysis is spastic or flaccid that total flaccid paralysis of a leg is rarely associated with dislocation at the hip and that the same displacement can be observed in the *sound* hip of a patient who walks for some years on an uncompensated short leg. It would seem, therefore that muscular imbalance is a main factor and not necessarily paralysis of itself Flaccid paralysis of the abductors in the presence of normally acting adductors produces the same effect as overacting adductors in the presence of normal abductors. Radiographs show the appearance of coxa valga as the lesion develops and support the view that failure of moulding of the femoral neck because of inefficient abductor muscular action is an important causal factor

In the early stages reduction can be effected by simple traction in abduction on a Jones double hip frame although in spastic patients tenotomy of the adductor origins will be necessary first Later manipulation under anæsthesia will be required. Unless fixation is maintained the hip inevitably redislocates with either of these methods. The most promising treatment (Blundell Jones 1954) is based on the recognition of the coxa valga deformity and consists of a subtrochanteric wedge osteotomy with its base inwards, in order to produce a relative varus effect this is held by the insertion of a miniature nail plate Compare Fig. 238 (*c*) Abduction of the leg to the normal walking position then reduces the femoral head and thus is maintained in a plaster of Paris case

Reference

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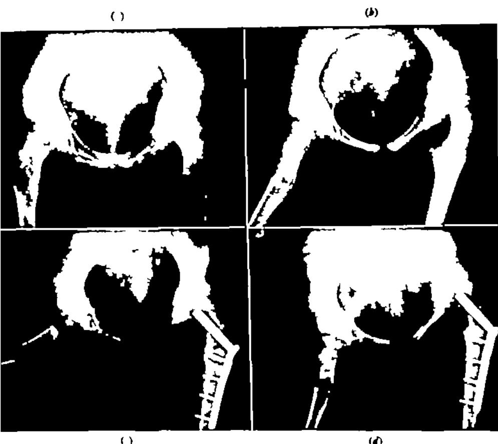
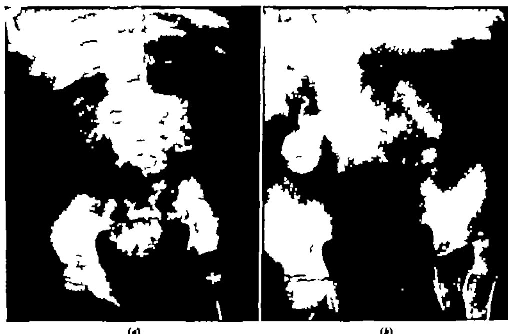


FIG 238 Four X-ray photographs of girl who had acute anterior poliomyelitis in 1948. (*a*) 8/49 to illustrate the osteoporosis of the leg in which all muscles were paralysed. (*b*) 1/54 to show increasing subluxation at the hip in the leg with partial paralysis. (c) 12/54, the subluxation of the hip reduced by subtrochanteric wedge osteotomy and internal fixation. (*d*) 2/55 Consolidation of the position. The nail plate has since been removed and the hip remains stable



(*a*) (*b*)

FIG. 239 X-ray photograph of boy with congenital spastic paraplegia and tuberculous spine who was recumbent from early infancy (*a*) 3/38 Illustrating the tuberculous focus and both hips in natural position with increase of the joint spacing on the left side. (*b*) 1/43 dislocation of the left hip



( )

FIG 239(*c*) 7/47 to illustrate commencing dislocation of the right hip and the formation of a false acetabulum on the left side.

CHRONIC DEFORMING ARTHRITIS

The hip may be involved in any of the chronic progressive non-pyogenic inflammatory lesions which affect joints. Sir Robert Jones and R. W Lovett (1929) discussed the subject in a chapter of their classic "Orthopædic Surgery" and it is significant that they used Arthritis Deformans as the title because "it begs no question of etiology or pathology" It is still important to preserve this open mind when considering these conditions to-day Four broad groups may be recognized and distinguished upon a combination of clinical, etiological radiological and pathological observations They all overlap but this is a useful basis upon which to discuss the matter

The warning symptom is aching pain, commonly worse at night and often referred to the knee. The clinical signs are centred upon painful limitation of movement which usually commences in the ranges of abduction and internal rotation, affecting flexion last of all and slowly leading in some patients to a flexion adduction deformity which occasionally reaches subluxation, in others to ankylosis by fibrous tissue or bone.

Chronic Osteoarthritis

This, the most common cause of a deformed hip may be observed to follow injury for instance a fracture of the acetabulum, congenital dislocation of the hip reduced or unreduced, Perthes disease and displaced upper femoral epiphysis. Thus mechanical incongruity of the joint surfaces suggests itself as one likely etiological factor even in those patients of late middle age who develop the condition without a precise history sometimes in a single hip The macroscopic changes include alteration in the quantity or quality of joint fluid hypertrophy of the synovial membrane and dull yellow roughened and split articular cartilage which finally disappears to leave hardened or eburnated bone in the centre of the articular surface. At the periphery of the articular surface the hyaline cartilage proliferates to form osteophytes.

The radiographic changes usually conform to one of three main types

(*a*) Large osteophytes form at the articular margins and the "joint space" is slow to disappear (Fig. 240)

(*b*) Few osteophytes are seen but the "joint space" diminishes at an early stage (Fig. 241).

(*c*) Changes reminiscent of aseptic necrosis appear in the femoral head with coxa vara deformity resembling that of displaced upper femoral epiphysis (Fig. 242).

All three are likely to show at one stage or another irregular rarefied, cystic areas in bone immediately adjacent to the articular surfaces of the acetabulum and the femoral head

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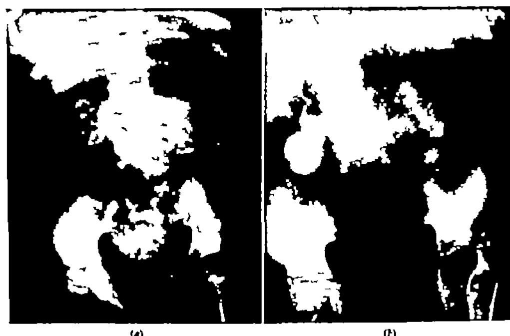
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(a) (b)

FIG. 39. X-ray photograph of a boy with congenital spastic paraplegia and a tuberculous spine who was recumbent from early infancy. (a) 3/38 illustrating the tuberculous focus and both hips in natural position with increase of the joint spacing on the left side. (b) 1/43 dislocation of the left hip.



(c)

FIG. 39(c). 7/47 to illustrate commencing dislocation of the right hip and the formation of a false acetabulum on the left side.

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The warning symptom is aching pain, commonly worse at night and often referred to the knee. The clinical signs are centred upon painful limitation of movement which usually commences in the ranges of abduction and internal rotation, affecting flexion last of all, and slowly leading in some patients to a flexion adduction deformity which occasionally reaches subluxation, in others to ankylosis by fibrous tissue or bone.

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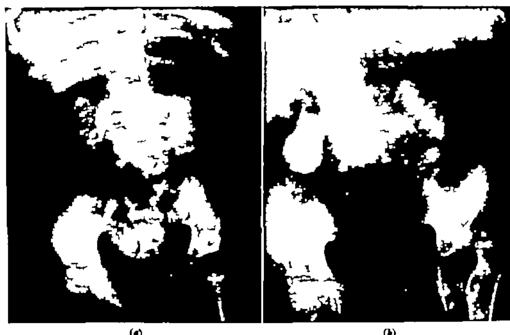
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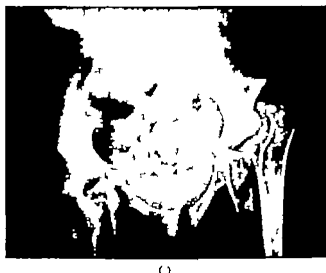
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CHRONIC DEFORMING ARTHRITIS

The hip may be involved in any of the chronic progressive non-pyogenic inflammatory lesions which affect joints. Sir Robert Jones and R. W Lovett (1929) discussed the subject in a chapter of their classic "Orthopædic Surgery" and it is significant that they used Arthritis Deformans as the title because "it begs no question of etiology or pathology" It is still important to preserve this open mind when considering these conditions to-day Four broad groups may be recognized and distinguished upon a combination of clinical, etiological, radiological and pathological observations. They all overlap but this is a useful basis upon which to discuss the matter

The warning symptom is aching pain commonly worse at night and often referred to the knee. The clinical signs are centred upon painful limitation of movement which usually commences in the ranges of abduction and internal rotation, affecting flexion last of all and slowly leading in some patients to a flexion adduction deformity which occasionally reaches subluxation, in others to ankylosis by fibrous tissue or bone.

Chronic Osteoarthritis

This, the most common cause of a deformed hip may be observed to follow injury for instance a fracture of the acetabulum, congenital dislocation of the hip reduced or unreduced, Perthes disease and displaced upper femoral epiphysis. Thus mechanical incongruity of the joint surfaces suggests itself as one likely etiological factor even in those patients of late middle age who develop the condition without a precise history sometimes in a single hip The macroscopic changes include alteration in the quantity or quality of joint fluid hypertrophy of the synovial membrane and dull yellow roughened and split articular cartilage which finally disappears to leave hardened or eburnated bone in the centre of the articular surface. At the periphery of the articular surface the hyaline cartilage proliferates to form osteophytes.

The radiographic changes usually conform to one of three main types

(a) Large osteophytes form at the articular margins and the "joint space" is slow to disappear (Fig. 240).

(b) Few osteophytes are seen but the "joint space" diminishes at an early stage (Fig. 241).

(c) Changes reminiscent of aseptic necrosis appear in the femoral head with coxa vara deformity resembling that of displaced upper femoral epiphysis (Fig. 242).

All three are likely to show at one stage or another irregular rarefied, cystic areas in bone immediately adjacent to the articular surfaces of the acetabulum and the femoral head.

The microscopical changes include round celled infiltration of the hypertrophied synovial villi, irregular proliferation of articular cartilage cells at the articular margins and later irregular ossification in the same area degeneration and death of cartilage cells in the centre of the articular area and sclerosis of bone where the cartilage has disappeared. Amongst the many workers who have given detailed descriptions of these changes, that of Collins (1949) is comprehensive. Trueta (1953) has recently drawn attention to the possibility that hyperæmia of bone is the forerunner of these changes and that, in order to preserve its vitality the articular cartillage of the hip needs to be alternately compressed and released. It is probably true to say that the analogy between

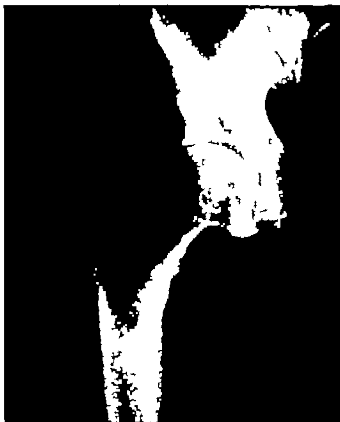


FIG 240. T illustrate the radiographic changes type A.



FIG 241 T illustrate the radiographic changes type B.



FIG. 242. Type C radiographic changes in both hips.

nanimate joint, whose bearing surfaces are worn and irregular and which is running and hot, and living tissue, can be most closely drawn in the case of the osteoarthritic where the whole process is one of degeneration and not disease

Chronic Rheumatoid Arthritis

Chronic rheumatoid arthritis involves the hips amongst many other joints Unlike :oarthritis, it does not appear in one hip alone The accompanying pyrexia, sweating, ting and blood changes indicate a metabolic disorder even if they do not, as some horities claim, originate in bacterial infection. Certainly the joints are destroyed by a cess very similar to pyogenic infection. A preliminary effusion of fluid renders the it hot and tender It is accompanied by intense muscle spasm and followed by the mation of a pannus of granulation tissue within the synovial membrane which eats way across the articular cartilage

Radiographs show an intense decalcification of bone not limited to the articular ends : spreading up and down the shaft (Fig. 243).

The whole process is quicker than the degeneration of osteoarthritis and results in kylosis, fibrous or bony very often in considerable deformity produced by the powerful iscle spasm. In the same patient it is common to see the condition "burnt out" in some nts but still active in others

Ankylosing Spondylitis

This is characterized by pain, pallor and anxiety It affects young and early middle ed patients reaching the hip joints only in its later stages. It is thought to be one of the llagen diseases and is accompanied by a great increase in the blood sedimentation rate

stopped short of pain and applied systematically preserve the range of movement and baths, massage and the spa regime benefit the chronic rheumatoid patient in general even if they do not improve the hip It must be emphasized that any improvement gained is temporary and that prolonged physiotherapy not only defeats its own object but minimizes the benefit that can be produced by more radical treatment applied at the proper time.

(*b*) SPLINTAGE. It is a truism that pain caused by chronic arthritis of the hip can be cured by complete rest but the means to gain this end, either by putting the patient to bed



FIG. 245 Radiographs to illustrate bilateral protrusio acetabuli developed late in life Female patient aged 45

or applying a complete plaster spica, immobilize so much of the patient that except in a few rare instances they are not worth while. Similarly relief from weight bearing by a caliper splint has a temporary effect but with the added disadvantage that if the splint is properly adjusted it tends to thrust the hip into just that adduction deformity which the surgeon seeks to avoid.

(*c*) MANIPULATION UNDER ANÆSTHESIA This form of treatment can be applied with safety to the hip only in the osteoarthritic variety of deforming arthritis and it should never be used in the others. The indications are difficult to define for manipulation is truly an art. In osteoarthritis the procedure is based upon the breaking down of intra-articular adhesions and the stretching of muscular contractures. If these are too dense a severe reaction follows and the joint becomes stiffer if they are too "young" they will reform. In an active patient whose hip shows some limitation of all movements without any deformity and whose muscles are of go[illegible] and tone temporary relief can be expected. It is to be emphasized that the[illegible] d be moved gently but firmly once through its wh[illegible] general

RADIOTHERAPY This has been tried and found wanting in all forms of chronic ing arthritis except ankylosing spondylitis where it is almost a specific and is to relieve the pain However the later effects of bone softening, pathological : and leukæmia cannot be disregarded

OPERATION The general indications for surgery in deforming arthritis of the hip actable and increasing pain and the appearance of deformity Certain procedures



FIG. 246. To illustrate the arthrodesis of a hip by combining ilio-femoral graft and osteotomy

been advocated solely for the relief of pain acetabuloplasty capsulectomy and ctomy They have not gained general support. It is widely held that no one opera an ever succeed in all arthritic hips and that having carefully assessed each individual it a choice must be made from arthrodesis, arthroplasty displacement osteotomy ne combination of these The first two necessitate operative dislocation of the hip st does not, a vital point in avoiding shock which is of the utmost importance in the y patient.

) **Arthrodesis.** In a vigorous patient up to the age of 50 years with one hip only ed, there is much to be said for this procedure The advantages of a painless stable e gained at the expense of all movement at the hip Some of this lost movement is

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(*d*) RADIOTHERAPY This has been tried and found wanting in all forms of chronic deforming arthritis except ankylosing spondylitis where it is almost a specific and is certain to relieve the pain. However the later effects of bone softening, pathological fracture and leukæmia cannot be disregarded

(*e*) OPERATION. The general indications for surgery in deforming arthritis of the hip are intractable and increasing pain and the appearance of deformity Certain procedures



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(1) **Arthrodesis.** In a vigorous patient up to the age of 50 years with one hip only affected, there is much to be said for this procedure The advantages of a painless stable leg are gained at the expense of all movement at the hip Some of this lost movement is

compensated by a mobile lumbar spine but it is to be observed that a stiff hip throws undue strain on the lumbar spine just as a stiff spine greatly increases the incapacity of an arthritic hip Uncertainty of result in this operation has been held a disadvantage by many authors. While this was true of the plain intra-articular arthrodesis nevertheless observation of the late results from Brittain s (1942) ischio-femoral technique and from the combination of an ilio-femoral graft with displacement osteotomy makes it clear that fusion can be relied upon if a graft and an osteotomy are added (Fig. 246). The nearer the graft is laid to the neck of the femur either above or below the more certain



FIG. 247 The radiograph of cup arthroplasty of the right hip five years after operation. The patient has good range of movement and is free from pain. Changes are to be observed in the left hip also.

the result. Fixation in a plaster spica is necessary until fusion has occurred The late results of Charnley's (1953) intra-pelvic displacement of the femoral head render this operation comparable to an arthrodesis and it can be considered as a useful alternative procedure.

(2) **Arthroplasty** Operations to regain movement in stiff joints have always attracted attention as the ideal treatment and nowhere more so than in the hip particularly when both hips are involved together with the lumbar spine a state of affairs which may occur in any of the varieties of deforming arthritis. The simplest form of arthroplasty at the hip is excision of the head of the femur Girdelston s (1940) operation pain is relieved and some movement provided at the expense of stability The operation is only of use in very elderly patients and a caliper splint is often necessary afterwards and adduction deformity is a risk. In order to stabilize the hi an osteotomy may be performed some time after excision of the femoral head (B 49) Good results are claimed for this operation. Smith-Petersen s (1948) m lasty has not fulfilled the hopes

raised at its introduction because it has not been sufficiently realized that metal placed in contact with raw cancellous bone produces progressive rarefaction and that muscles will tend to reimpose on any false joint the deformity with which they were previously associated in the natural one In a minority of patients the operation results in a stable painless hip with a useful range of movement (Fig 247) in a majority it falls far short of this. Quite apart from the complications of dislocation of the cup, failure of the metal and progressive rarefaction of bone, recurrence of deformity and instability are the main difficulties.

An attempt may be made to overcome recurring deformity by using a posterior approach to the hip, removing the greater trochanter and reattaching it lower down and more posteriorly on the femoral shaft, which is held in abduction after the manner of Whitman (1919) and to avoid progressive rarefaction of bone by using a cup which fits the untouched acetabulum later shaping the femoral head to fit the cup If the excavation of a new acetabulum is rendered unnecessary then one of the main causes of shock is eliminated the other deliberate dislocation of the hip, remains and should be obviated as far as possible by a slow and gentle manœuvre The mold arthroplasty remains a useful procedure for one hip in bilateral deforming arthritis, the other hip already having been rendered painless and stable and it can be considered in any arthritic hip where deformity has not yet occurred It should be modified as experience demands rather than discarded.

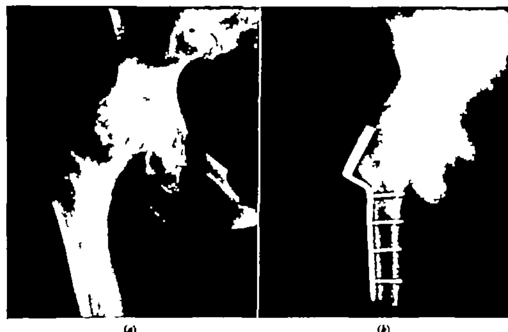
The Judet (1952) prosthesis has rightly been withdrawn from general use because the study of patients shows that it disintegrates or becomes unstable within three years of its insertion. The only remaining indication for this operation is a very painful hip in an aged patient whose prospect of life is limited to that short length of time

(3) **Displacement Osteotomy** This procedure has the advantages of relieving pain correcting deformity and stabilizing the hip without any intra articular interference which makes it singularly applicable to elderly patients. The study of late results (Wardle 1955), suggests that indirectly it favourably affects the articular cartilage of the femoral head and acetabulum so that an increase in the range of movement occurs. The disadvantages of this operation are held to be the necessity to fix the hip in a plaster spica for at least two months, with resulting stiffness of the knee and genu valgum they are probably over rated.

Whatever view is taken of the mechanics of this procedure a successful result in displacement osteotomy is associated with the conversion of the varus angle between the neck and shaft of the femur into valgus. Particular care is therefore necessary in choosing the site of osteotomy and the inclination of the line of bone section to the long axis of the femur A lateral approach, the skin incision diverging medially towards the anterior superior spine as it passes proximally over the greater trochanter is necessary in order to develop the area of the lesser trochanter so that the calcar femorale may be divided completely at the medial end of the bone section Failure to do this prevents proper displacement. The hip must be immobilized with the leg in abduction until union is present. When the limb is brought back to weight bearing line the femoral head is carried into the adducted position another feature constantly observed in all successful results

The possibility of combining that relief of pain restoration of stability and correction of deformity commonly the result of an arthrodesis with the retention or even increase of the existing range of movement at the hip joint cannot be lightly disregarded in our

present stage in the treatment of deforming arthritis of that joint. When the combined effect can be produced by a single operation which can be applied to even elderly patients with a minimum of risk then that procedure becomes the operation of choice. Displacement osteotomy can be applied to both hips in one patient if proper care is taken in the selection of the site and angle and suitable internal fixation is safe and successful in those patients too old to tolerate a plaster spica (Fig. 248).



(*a*) (*b*)

FIG. 248. Radiograph to illustrate (*a*) an advanced chronic osteoarthritis of the right hip in a patient aged 80, and (*b*) the appearance of the joint three years after a displacement osteotomy with internal fixation

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CHAPTER XIII

THE KNEE JOINT

LAWSON DICK

DERANGEMENT OF THE KNEE

The knee is the largest hinge joint in the body is structurally the least stable, an active adolescents and adults is normally subjected to the heaviest and most dama stresses of any of the weight-bearing joints. It is not surprising, therefore that dera ment of the knee is of frequent occurrence rather indeed, it is a matter for wo that the condition is not more common.

Because of its unstable bony structure the knee depends for its stability upon capsule, the ligaments (intra-articular and extra-articular) and the muscles contro the joint of the muscles subserving this function the quadriceps femoris is the important. The other factors which influence the stability of the knee are the syno of the joint, the menisci, and conditions affecting the articular cartilage of the fen condyles and the patella and rarely of the tibial plateau Because derangement o knee is almost invariably the result of trauma it is more common in males than in fem it happens at a time of life when heavy muscular exertion is undertaken and it is al confined to those whose activities, either in work or in play subject the knee to st rotational stresses. Another causal factor is the suddenness with which these str are brought to bear Skiers, footballers, and miners are examples of those whc commonly affected, whilst weight lifters, dock labourers, and mountaineers are r less frequently smitten. The stresses to which the latter subject their knees are not less in degree the difference lies in the suddenness with which the strain is imposed, on the probability of the muscles being caught off their guard.

The Extensor Mechanism of the Knee

By far the most important factors in preserving the stability of the knee join the tone and the power of the quadriceps femoris. This strong muscle has much t with the maintenance of the upright stance and orthograde progression which peculiar to mankind. It is true that other mammals may stand and walk on two but man is the only species that does so for preference. Dogs, bears, and eleph as a visit to a circus will show can walk on two legs, but it is not their natural and they do not do it well or happily Even monkeys and apes, which quite comm stand on their hind limbs, much prefer to be quadruped or to brachiate In fact of them fully extends the hip and knee joints.

Thus it follows that man possesses the most highly developed quadriceps femo all mammals and in particular the quadriceps in which the internal component vastus medialis, is most bulky and strong. The reason for this larger medialis comp is that this segment of the muscle is concerned with the final few degrees of exte of the knee. The knee can be straightened to within 5° to 10° of full extension by

other three parts of the quadriceps muscle and they are capable of extending the knee powerfully and against strong resistance within this range But all this time the knee remains unstable—the capsule and the ligaments are lax, and the knee is vulnerable to sudden unexpected strains. Only when the knee is braced into full extension aided by the rotatory locking of the tibia by the contraction of the vastus medialis does the joint become absolutely stable so that tibia and femur move as one bone, and only in this position is the knee safe from deranging strains. If enough strain is applied to the limb whilst the knee is held in full extension, something will break or give, the leg bones, the femur the ankle joint, or the hip joint, but the knee will escape damage.

There is a close association, probably through neurogenic reflex pathways, between the quadriceps muscle and the synovium of the knee joint. An inflammatory reaction in the synovium or an effusion within the knee cause very rapid wasting of the quad riceps femoris. This wasting occurs much more rapidly than could be accounted for by simple disuse atrophy of the muscle. It may amount to the loss within a day or two of an inch or more of the circumference of the thigh. This phenomenon is commonly seen in injuries to the knee and in infections of the joint, particularly tuberculous infection.

It is a pathological axiom that when functions are gradually lost in the locomotor system they are lost in the reverse order to that in which they are phylogenetically acquired. We have seen that phylogenetically the highest function of the muscles controlling the knee in man is that possessed by the vastus medialis in its power of holding the knee rigid in full extension. This portion of the muscle is therefore the first to waste and the power of full extension of the knee is lost. This means that the knee cannot be completely stabilized and is therefore vulnerable to rotational strains, either weight bearing or not. If the initial injury was simply a minor strain of the joint with a nipping of the synovium and a traumatic effusion, at once a vicious circle is established. The knee has swelled because of synovial trauma because of the resulting effusion in the knee joint the quadriceps and particularly the vastus medialis lose tone and power because the vastus medialis tone and power are diminished the knee is more easily damaged by stresses applied to it and there is further trauma to the synovium. The only point at which this vicious circle comes within the patient s voluntary control is in the function of the quadriceps muscle. Only when the quadriceps is again able to protect the knee is recovery possible, and for this reason the tone and power of the vastus medialis must be preserved or redeveloped.

Herein lies the important significance which attaches to the proper performance of quadriceps exercises in all knee derangements and in the period of recovery from all operations upon the knee joint apart from arthrodesis. It is essential to instruct patients how to perform these exercises properly *before* the knee sustains the trauma to the synovium which is inevitably caused by the operation, so that immediately afterwards they can begin to carry out the routine which they know will be required of them.

So important is this need for the maintenance of full tone and power in the quadriceps that the manner of performing quadriceps exercises must be clearly understood. More often than not the patient lies on his back and raises the lower limb in the air and is thought to be performing "straight leg raising" exercises. It happens almost invariably unless precise instructions are given and meticulous care is taken to see that these instructions are carried out, that the exercise is performed with the knee a few degrees short of full extension. If the exercise is carried out thus the patient uses the iliopsoas

muscle to flex the hip and three of the heads of the quadriceps, but *not the vastus medialis* and wasting of this muscle is not prevented In consequence the patient remains unable to brace his knee into full extension.

The physiotherapist or the surgeon must show the patient the correct method of obtaining full contraction of the vastus medialis. Most patients when asked to brace the knee into extension accompany the attempt by plantar flexion of the ankle This, by contracting the gastrocnemius tends to flex the knee. The correct method is for the ankle to be dorsiflexed and then for the patient to attempt at the same time to press the back of his knee on the bed and to raise his heel off the bed. Many people can actually do this, but even if the heel does not clear the bed the vastus medialis must be thrown into full contraction. The exact performance of this routine as described is of far greater importance than any form of pulley weight, or spring resistance which could be devised Indeed the latter are often more a hindrance than a help as they tend to distract attention from what is the essential feature of the drill contraction of the vastus medialis. It is, fortunately now almost superfluous to add that this exercise should be performed regularly and methodically for a period of five minutes in every waking hour It must be remembered that the quadriceps can be exercised satisfactorily even if the limb cannot be moved because of splinting. If the splint be a plaster spica, the knee can be braced back against the plaster so that all the components of the quadriceps are thrown into full contraction. Often it is convenient to cut a window over the patella and the inner side of the supra patellar pouch so that the behaviour of the vastus medialis may be under direct observation.

Not infrequently patients, even if they have been thoroughly taught and are practised in quadriceps drill lose the knack of contracting the vastus medialis after operation. This loss of knack may not be immediate. They may be able to contract the muscle for the 24 hours after awaking from the anæsthetic, and then suddenly find that they have lost control of it. This condition has been called "cerebral dissociation" the patient has "lost the feel" of full quadriceps contraction. The complication can always be overcome by proper treatment, but it must be tackled promptly and is one of the occasions when the assistance of a good physiotherapist is beyond price Sometimes the affected limb can be re-educated directly Sometimes a demonstration on the other limb of what is required restores the knack. Sometimes the aid of a faradic current is needed. The reason for the use of electrical stimulation should, however be clearly understood Its object is not to replace the patient's own voluntary muscle contraction, but rather to restore to him the sensation of the contraction of the vastus medialis. As soon as the cerebral dissociation is overcome the artificial contractions are replaced by the patient's own voluntary muscular effort.

THE EXTRA ARTICULAR LIGAMENTS OF THE KNEE

The quadriceps femoris is inserted into the leg bones by means of (1) the patellar tendon and (2) the extensor expansion These two insertions are of almost equal importance. The heavy central patellar mechanism does not here need emphasis the ensheathing cuff of capsule called the quadriceps expansion merits special consideration. This funnel-shaped fibrous sheath receives directly a large portion of the insertion of the quadriceps femoris, particularly of the vastus medialis, and is thus intimately concerned with the maintenance of stability There are, as there are in most hinge joints, two

lateral condensations of this capsule in which the fibrous tissue is increased in thickness and in strength and which have been described as individual structures and are called ligaments. It is important to note, however that they have no definite edge but merge gradually into the capsule of which they are merely local thickenings. Naturally they are placed where the capsule is most subject to lateral strains, and where its integrity is of importance to the stability of the joint.

Tibial Collateral Ligament

The tibial collateral ligament is attached to the inner surface of the inner femoral condyle and to the inner edge of the head of the tibia. It is a broad strap-like structure. The fibular collateral ligament is attached to the external aspect of the lateral femoral condyle and to the proximal tip of the head of the fibula. It is a narrow and cord-like structure. As will be seen later the periphery of each meniscus is attached to the deep surface of the corresponding ligament.

Because the knee is much more often subjected to violence in a valgus direction than to varus strains the internal collateral ligament is injured much more commonly than the outer Only injuries of the medial ligament will therefore be considered in detail, but the observations about diagnosis and treatment apply almost equally to the much rarer injuries of the outer ligament. The degree of injury depends upon the amount of violence sustained and varies from a simple strain, through a partial rupture, to a complete tear of the ligament.

Diagnosis and Treatment. Early and precise diagnosis is essential if treatment is to be accurate and effective There is a history of injury there is usually an effusion in the joint, the knee is not locked, i.e there is no block to complete passive extension of the joint, and there is extreme tenderness on pressure over the internal collateral ligament, usually nearer to the femoral than to the tibial attachment. Radiographic examination may show no bone injury If however there is an avulsion fracture of the cortex of the inner femoral condyle then there is proof of an actual tear at the attachment of the ligament, but this is uncommon. Thus far then, there may be no sign by which the surgeon can distinguish between a sprain, stretching, or partial rupture of the tibial collateral ligament and a complete tear of the ligament. But it is of vital importance that the diagnosis be precise If the injury stops short of complete tear of the ligament the lesion will heal if the knee is protected in a plaster cylinder for six weeks and regular quadriceps drill is performed. Recovery will be full. If however the ligament is torn across, this treatment will not restore the knee to full stability and permanent disability will result. The reason is that the torn ends of the ligament curl and retract, and if this injury is treated conservatively there is a permanent gap with consequent irremediable instability of the knee. It is true that active development of the quadriceps by regular quadriceps drill will, to some extent, mitigate the effects of the deficiency but the knee will always be unstable and will be liable to derangement. Early recognition of the lesion by radiological demonstration of its presence and early repair by open operation are needed if the result is to be one of perfect restoration of function.

The radiological examination should be carried out under full general anæsthesia because the recently injured knee is too painful to allow of adequate manipulation without it To demonstrate a ligamentous lesion the examiner places one hand on the outer side of the knee and grasps the leg with the other hand so that he may apply

valgus strain to the joint. When this strain has been applied it may be possible to determine by feel that the tibia can be tilted outwards on the femur but the finding should always be checked by radiography. The normal knee tilts not more than 5 degrees; any excursion over that is suspect and a tilt of 10 degrees or more is certainly pathological.

The lesser degrees of tilt can be treated conservatively by immobilization of the knee in a plaster cylinder and by the institution of the routine of quadriceps exercises. If, however, there is a tilt of 20 degrees or more it may be assumed that there is a partial or complete rupture of the internal collateral ligament and the ligament should be explored by operation. The tear is usually found in the upper part of the ligament just below its femoral attachment and the repair consists of re-attaching the torn inferior portion by 2 or 3 interrupted sutures. The procedure is easy in the early stages, but may be impossible if operation is delayed for a week or more. It cannot be too strongly emphasized that the only object of operation is to prevent downward retraction of the torn ligament and that the sutures are intended only to hold it in place until it heals under the protection of splinting by a plaster cylinder.

Fibular Collateral Ligament

When the outer ligament of the knee is torn the management of the injury is exactly similar to that which applies to the internal ligament. There is, however, an important complication. The external popliteal nerve runs across the postero-external aspect of the joint, and when the outer ligament of the joint is torn the nerve is frequently damaged. This injury may be a simple traction lesion without solution of continuity of the nerve sheath, or it may be a complete tear of the nerve. In either case there is loss of power of the peronei and of the dorsi flexors of the ankle and the toes, and diminution of sensation over the cutaneous distribution of the peroneal nerve. This motor and sensory loss is complete if the nerve is torn, but it may also be complete with a severe traction lesion. If the nerve is torn across it should be repaired by open operation; if it is only stretched the lesion may be treated conservatively. If there is serious doubt about whether or not the nerve is torn it should be explored by operation and if a tear is found it should be sutured. Traction lesions are treated conservatively. In either event the paralyzed muscles must be protected by suitable splinting until they recover and in both the prognosis is poor. The sensory loss is not widely enough distributed to be of great moment, but recovery of power in the affected muscles is very slow indeed, and commonly at least some degree of motor weakness may be permanent. If the lesion is treated conservatively and a traction neuroma develops it should be excised, and the nerve sutured. It must be remembered, however, that recovery in traction lesions may not appear till a year or more after injury. If the paralyzed muscles are suitably protected there is no urgency about late exploration of the nerve, and if they have not been protected nothing useful will be achieved by operation upon it.

The Intra-articular Ligaments of the Knee

These are the anterior and posterior cruciate ligaments, which are strong fibrous bands that cross each other in the middle of the joint. They are intra-articular but are extra-synovial.

The *anterior cruciate* ligament is attached to the tibial plateau just in front of the

tibial spine and runs upwards, backwards, and laterally to its proximal attachment to the inner side of the outer femoral condyle. It is the stronger and the more important of the cruciate ligaments. Together with the posterior capsule of the joint it limits extension of the knee, and it controls the forward movement of the head of the tibia on the femur. It is commonly injured in severe disruptive lesions of the knee such as fracture-dislocations of the joint, but it may be sprained, or partially or totally ruptured as an isolated injury. In adolescents and young adults the lesion more commonly takes the form of an avulsion of the tibial attachment together with a fragment of the tibial plateau.

When this avulsion fracture occurs the avulsed fragment can commonly be replaced simply by passive extension of the knee. When the fragment does not re-embed itself it may have to be replaced by open operation. It is usually preferable not to use any form of internal fixation. The commonest barrier to re-position is that the avulsed fragment is tilted, but when this tilting is corrected the fragment remains snugly replaced. If there is any doubt about the accurate replacement of the fragment the joint should be opened without delay. Whether a fragment of tibia is avulsed or not, there is a hæmorrhagic effusion in the joint, and the diagnostic sign of the lesion is that *the tibia can be moved forward on the femur either with the knee flexed or with the knee extended.* Whether open operation is needed or not the knee is protected with a plaster slab or in a plaster cylinder for 8 weeks, and regular quadriceps exercises are at once begun. Weight-bearing may be allowed after the effusion has subsided and when quadriceps tone and power are restored to normal.

This is a serious injury and one which is liable to leave the knee prone to derangement by further articular damage, such as a tear of a meniscus. It is therefore of the utmost importance that the tone and power of the quadriceps, and in particular of the vastus medialis, should be fully maintained, and a patient who has sustained a lesion of the anterior cruciate ligament should make regular quadriceps drill a part of his or her daily routine indefinitely. By this means the effects of the ligamentous weakness are minimized and the patient is enabled to engage in most forms of activity without undue hazard.

The idea of repair of a torn cruciate ligament by operation seems theoretically attractive, and several methods have been described, either for replacement by a fascial graft, or for tenodesis by re-routing one of the ham-string tendons. None of these methods has in practice proved to be satisfactory and there is no doubt that late instability of the knee due to a lesion of the anterior cruciate ligament is best treated conservatively by intensive quadriceps drill continued indefinitely.

The *posterior cruciate* ligament runs from the tibial plateau behind the tibial spine almost directly upwards and slightly inwards to be attached proximally to the outer aspect of the inner femoral condyle in the intercondylar notch. It is of much less importance than the anterior cruciate ligament, and is much smaller. The posterior cruciate ligament becomes taut when the knee is flexed, but hyper-flexion of the knee is not possible anyway because of approximation of the calf to the back of the thigh, so its function in limiting flexion is unimportant. It also limits backward migration of the head of the tibia on the femur. It is seldom injured alone, but it may be torn as a part of a multiple injury of the knee. The treatment of a lesion of this ligament is simply by redevelopment of and care in maintenance of the tone and power of the quadriceps femoris.

THE MENISCI

Injury to the semilunar cartilages is the commonest cause of derangement of the knee joint The cartilages are wedge-shaped structures which are designed to occupy the spaces at the sides of the knee joint where the femoral condyles curve upwards from the tibial plateau. In the developing fœtus and in early post natal life they are discoid in shape, but as weight is borne on the lower limbs the centres of the discs are absorbed and the cartilages assume their adult semilunar shape. Sometimes the outer cartilage remains discoid—when it does so it may give rise to trouble this condition will be discussed in detail later

The *inner cartilage* is attached at either end of the tibial plateau in the middle area of the articular surface close to the anterior edge and close to the posterior edge in front of and behind the corresponding attachments of the outer cartilage. The periphery of the meniscus is attached to the inner aspect of the capsule and of the internal collateral ligament. The horns are attached by avascular fibrous bands, and the periphery is attached by short horizontal vascular strands known as the coronal fibres. Because of the wide separation of the cornual attachments and of the firm coronal attachment which extends all the way around its periphery the internal cartilage is very firmly fixed to the tibia and normally cannot move independently of it. When the tibia is rotated on the femur the internal cartilage rotates with the tibia.

The *outer cartilage* has a similar attachment to the tibia, but there are important differences. The anterior cornual attachment is behind that of the inner cartilage, and the posterior cornual attachment is in front of the posterior attachment of the inner cartilage. The central fixed points are therefore much closer together than are those of the inner cartilage. The peripheral attachment of the outer cartilage to the inner aspect of the outer capsule is not nearly so close as is that of the inner cartilage. Moreover there is a gap in it, the popliteal hiatus through which the tendon of the popliteus muscle passes. In consequence the outer cartilage is more mobile than the inner and does not follow the rotational movements of the tibia as closely and intimately as does the inner cartilage

As a result of its greater fixation the inner cartilage is more liable to injury than is the more mobile outer cartilage The ratio of injuries to the inner cartilage to that of injuries to the outer is about as nine is to one. On the other hand, the outer cartilage is more liable to be affected by congenital anomalies such as persistence of the fœtal discoid shape or by degenerative changes such as give rise to mucoid cysts. Also, in considering cartilage injuries, it must be borne in mind that the basic anatomical structure of an individual knee has much to do with the occurrence of cartilage tears. Some men have constitutionally lax knees and are more liable to sustain cartilage tears than those whose knees are more stable. Thus it is not unusual to find a patient who may have independent tears at different times in both cartilages of one knee or in two cartilages in both knees, or even in all four cartilages.

The Internal Meniscus

Tears of the inner cartilage are caused by violent rotation of the femur on the fixed tibia with the knee in flexion. The cartilage remains fixed to the tibia, and the rotatory stress of the femoral condyle ruptures it. Hence tears of the inner cartilage are normally

towards the periphery and, because the strain is most commonly internal rotation of the femur on the fixed tibia, initially at the posterior end of the meniscus. It must be remembered that the peripheral attachment of the inner cartilage is by vascular coronal fibres, and that therefore a first tear of an internal meniscus may heal if it is given the opportunity The tearing of the cartilage is normally a sudden, dramatic and painful incident, akin to the fracture of a bone, and it occurs so in footballers, skiers, tennis players, and those who stumble or trip on uneven surfaces, but it can occur insidiously and in a manner reminiscent of that in which a stress fracture happens. The commonest example of this is in the coal miner who works for long spells crouched on his haunches and, when he attempts to rise, finds that he cannot straighten his knee. The cartilage tears in a similar quiet way in housewives.

Diagnosis. By far the most important single factor in arriving at a diagnosis of a tear of a semilunar cartilage is the history There is very frequently but not by any means always, a history of injury often with a story that the patient "felt something go" in the knee. Usually he is momentarily or even longer than momentarily unable to straighten the knee completely and if he tries to walk has to do so on tip-toe on the injured limb. Frequently but again not invariably he can tell on which side of the knee the tear has occurred sometimes the pain is too severe for him to be able to localize it. If the lesion happens during a game, say football, the patient can very often continue, but cannot exert himself fully—often he says that he "just hobbled on the wing" to which he had been transferred. An effusion appears in the joint very rapidly and may be of considerable size. Usually the patient is laid up for a week or so and then gradually resumes activity as the effusion subsides.

Thereafter however the knee does not feel dependable. He cannot trust it. Incidents of "giving way" are usually followed by some effusion. If the tear is large enough to allow the bulk of the cartilage to be displaced into the centre of the joint, the knee may lock in flexion. This "locking" means that the joint cannot be extended fully either actively or passively It may happen during activity or quite quietly when the patient turns over in bed, or he may find the knee locked when he tries to rise from a low chair The patient may be able to replace the torn portion of cartilage himself by kicking the knee straight, or it may be replaced by manipulation either without or with anaesthesia. Forcible manipulation, however commonly results in a false reduction. The torn portion of cartilage is not replaced, but the tear is increased and the torn fragment is displaced into the intercondylar notch. If this is the result of the manipulation the knee will continue to derange These incidents, whether the locking is spontaneously reduced or not, or even when it is no more than a "giving way" of the knee, are followed by effusion which tends to decrease in amount each time the knee deranges.

The patient can almost always localize the lesion with certainty to the affected side of the knee. This is most important and dependable diagnostic evidence. It is noteworthy also that patients are less certain about tears of the outer cartilage than they are of the inner and that in general the further back in the cartilage the tear is sited the less is the patient able to be sure of which side is affected.

There is almost always some effusion In a recent tear this effusion is gross the longer the lesion has been present the less in amount is the effusion which follows the repeated derangements, but there is almost always some Several methods of detecting effusion in the knee joint are described, but the most reliable is that of the "patellar tap."

The examiner puts one hand on the supra patellar pouch and expresses the fluid downwards out of it, and with the fingers of the other hand gently thrusts the patella back against the femur Normally the articular surfaces are in contact, or are separated by so little synovial fluid that the patella cannot be felt to move. If there is an effusion in the knee the patella can be felt to bob back against the femur—a sensation quite unmistakable to the trained observer Of course, the effusion may be so gross that the patella cannot be made to come into contact with the femur but in this event there is not any difficulty in recognizing the presence of the fluid

There is almost invariably localized tenderness, sometimes so sharply delimited that it is found only in an area of about the size of the pad of the finger This tender area is located on the joint line in the region of the crossing of the internal collateral ligament over the joint, either in front of the ligament or behind it, depending upon where in its periphery the cartilage is torn. This is an important sign, and the fact that the tender area is located on the joint line serves to differentiate between cartilage tears and strains or tears of the internal collateral ligament in which the tenderness is more commonly elicited on pressure over the inner femoral condyle. Moreover after the tender spot associated with a cartilage tear has been found, the patient not infrequently volunteers the information that he had been aware of a "bruised feeling" in that region since his knee began to give trouble

Rotation Test. This test, described by and associated with the name of the late Professor T P McMurray of Liverpool depends upon the fact that the torn cartilage is abnormally mobile, and "McMurray s sign" is elicited by a passive demonstration of that mobility The patient lies on his back. The examiner takes the foot of the affected limb in one hand and puts his other hand over the knee so that the finger tips lie on the joint line. The tibia is then rotated on the femur internally and externally while the knee is passively flexed and extended. The positive findings may be either *subjective* or *objective* or both. The examiner may feel the cartilage slip under his fingers. A clicking sensation may be felt or there may even be an audible clicking sound, heard not only by the examiner and the patient but by bystanders. These are the positive objective findings, and they are very dependable The positive subjective findings are that even if a click is not elicited the attempt to produce it causes the patient pain at the site of the lesion, and this pain may be such as to produce muscle spasm sufficient to make proper performance of the test impossible. Nevertheless, this induced pain and spasm are valuable positive information and may be enough, along with the history and other signs, to confirm the diagnosis.

Radiographic Examination. Radiography of the knee is essential if diagnostic errors are to be avoided. There is no positive radiological appearance of a cartilage tear but X-ray excludes other conditions which may cause similar symptoms, osteochondritis dissecans, loose body chondromalacia patellæ osteoarthritis, or a pathological fracture in an osteoclastoma of the femoral condyle. It should be remembered, however that osteoarthritis is a late result of recurring cartilage displacement, and the fact that a knee is osteoarthritic does not necessarily mean that a torn cartilage should not be removed if a positive diagnosis of tear is indicated by the history and the physical examination. Attempts have been made to demonstrate cartilage tears by contrast radiography but arthrograms are disappointing. The technique is difficult and time-consuming. A reliable standard of radiography can be obtained only by the same surgeon working

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always under the same conditions with the same radiographer The pictures are difficult to interpret, especially so in the doubtful knee in which help is most needed, and the experienced surgeon will make fewer mistakes if he depends upon an accurately elicited history and on careful physical examination

Treatment. When a patient is seen immediately after the first incident, treatment should be conservative unless the knee is obstinately locked. If it is, the cartilage has been torn and widely displaced and should be removed. Operation is not, however a matter of urgency It is better that the patient be put to bed and the knee protected from weight-bearing until the immediate post traumatic effusion has subsided—usually a period of about 1 week is enough. During this time quadriceps drill is practised.

If the knee is not locked then the displaced cartilage has been replaced, either spontaneously or by manipulation It has already been said that the commonest site of a tear is in the periphery of the meniscus, in the region of the vascular coronal fibres. Because this area is vascular the tear may heal. It is thus sound practice to splint the knee in extension for some 4 weeks, allowing the patient to bear weight after the effusion has subsided, and then to let him resume normal activity If the tear heals the cartilage may not cause any further trouble.

If there is more than one incident of derangement the cartilage should be excised. Secondary healing of a torn cartilage does not occur and the more often the knee deranges the more does the joint sustain permanent damage. It is not necessary here to describe the operation in detail I intend only to indicate a few of the more important points. A tourniquet is essential. It is not possible to remove a cartilage with accuracy if the operation field is obscured by blood. As Sterling Bunnell said, "You don't fix a watch in a bottle of ink. The use of a sucker is a much better method of dealing with effusion fluid than is swabbing. The sucker is more efficient than swabs, and it is bacteriologically safer in that it can be boiled. Operations on joints need the highest standard of asepsis, and nothing that is not absolutely sterile should be inserted into the knee joint. The incision should be as small as is compatible with adequate exposure the smaller the synovial wound the less is the post-operative reaction. On the other hand, the incision should not be too small. Access to the joint should be adequate because considerable damage may be done to the synovium by over head retraction. The whole meniscus must be removed. It is not enough to remove the portion which has been detached by the tear for the remaining rim may be the site of secondary tears. If for any reason the whole cartilage cannot be removed through the anterior incision there should not be any hesitation in making a second incision over the posterior end of the cartilage

The surgeon must be prepared to rely on his pre-operative diagnosis. He must not be dismayed if when he first opens the joint, the anterior part of the cartilage looks normal. Many of the posterior tears are seen only after the anterior horn is detached and the meniscus can be drawn forward into the incision. Pre-operative diagnosis must be exact and dependable, and the whole meniscus should be removed with the least possible operative trauma.

The essentials of the *post-operative routine* can be covered in a few words (1) regular quadriceps drill with meticulous attention to the function of the vastus medialis (2) protection of the knee from weight-bearing until the post-operative effusion has

subsided Some surgeons allow the patient to walk early It is better however to have the knee held straight in a firm compression bandage with some light form of splinting and that weight-bearing should not be allowed until 10 days have elapsed. Then the sutures are removed, and flexion of the knee is begun If this does not cause an effusion weight bearing may be gradually resumed but the rate of progress of remobilization must be governed by how the knee reacts. If there is no swelling progress may be rapid If the knee swells progress in weight-bearing should be halted, and non-weight-bearing quadriceps exercises should be resumed until the effusion again subsides.

Hæmarthrosis. This post-operative complication requires special mention. The signs which arouse suspicion are (1) low grade pyrexia (2) loss of quadriceps control (3) undue pain (4) swelling distal to the compression bandage. If hæmarthrosis is seriously suspected the dressing should be removed and the knee inspected in the operating theatre. If it is confirmed the blood should be evacuated through a wide-bore aspirating needle, and then the pressure bandage should be replaced. If bleeding into the joint is not recognized and is not so treated recovery is greatly prolonged and, due to the formation of intra-articular adhesions, may never be perfect.

The External Meniscus

Most of what has been written about the internal meniscus applies equally to lesions of the external meniscus but a few important differences should be noted That the outer cartilage is less frequently torn than the inner has been referred to We have also seen that there is normally a gap in the peripheral attachment of the outer cartilage, the hiatus for the popliteus tendon By far the commonest site for a tear in the outer cartilage is behind this hiatus, and the detachment is normally complete. There is seldom enough of a peripheral rim remaining to carry a secondary tear and to cause trouble. A posterior incision is therefore rarely needed, but if there is any doubt about the completeness of the removal of the cartilage a second incision must be made just as on the inner side.

Cysts of the External Meniscus. Tears of the outer cartilage are very often accompanied by degenerative cysts in the cartilage. It is frequently not clear which happened first, the tear or the degenerative change, but the order of sequence does not matter as the treatment for both conditions is the same, namely excision of the cartilage. A degenerative cyst almost always occurs in the anterior half of the meniscus The predominant symptom is pain in the knee located to the front of the joint line on the outer side and often there is a visible and palpable tender swelling. The pain, the tenderness and the local swelling are all increased by exertion.

Operative removal of the cyst alone is useless—the whole cartilage must be excised If only the cyst is removed it will form again in what remains of the cartilage. Further if there is an associated tear of the meniscus, the knee will continue to cause trouble

Discoid External Meniscus. If the central portion of the cartilage is not absorbed as weight bearing begins, the meniscus, instead of becoming semilunar in shape, remains discoid In addition to having too great a surface area these atavistic cartilages are almost always thicker than normal, and occupy too much space in the outer compartment of the knee. They usually manifest themselves in adolescence, that is to say when the child begins to be more vigorous in games and athletics. The commonest symptom is a painful clicking on the outer side of the joint. The mechanism by which this is produced is that as the knee straightens the femoral condyle compresses the thick fleshy

ilage in front of it until it suddenly slips over the ridge in the cartilage which is so duced. If this state of affairs is allowed to continue the cartilage will inevitably tear ually the pain and inconvenience of the clicking knee are such that the patient is ught for advice before the cartilage tears. The condition can be recognized from the ory the clicking is easily reproduced on physical examination, and the treatment is ernal meniscectomy

Persistence of Derangement after Meniscectomy

If the knee continues to derange after meniscectomy there are several possible causes

(1) Wrong or incomplete diagnosis. Both menisci may be torn and only one tear may e been recognized. A loose body or a patch of osteochondritis dissecans may have n missed. Incomplete operation cannot be followed by complete recovery

(2) Quadriceps insufficiency or ligamentous laxity The first should not occur and second should have been recognized before operation. The treatment for either is driceps drill.

(3) The derangement may in fact have been due to chondromalacia patellæ or to urring subluxation of the patella (*see* page 439)

(4) A mobile posterior fragment of cartilage may have been left in the joint. This uld not happen, but if it does the fragment must be removed.

(5) The reformed cartilage may be torn. When a meniscus is removed it is replaced ı rim of fibro-cartilage. This rim is narrower than the normal cartilage, and is much re firmly attached at its periphery but it is of much the same shape as a normal ilage and very occasionally it is torn in the same way as a normal cartilage If this ortunate accident happens the torn re-formed cartilage must be excised

OSTEOCHONDRITIS DISSECANS AND LOOSE BODIES

The pathology of these conditions is discussed on page 336 In the knee they seldom se true locking the symptoms are those of a feeling of instability and of the knee ng way usually with recurring effusion. The characteristic feature of the history hat the patient cannot be precise about where in the knee the derangement occurs, ough he usually complains of "something moving in the joint."

The diagnosis of both conditions rests ultimately on the X ray appearances. If a se body is seen it should be removed. This operation should be carried out under X-ray trol the loose body must be localized by an X-ray photograph taken on the operating le *after* the tourniquet has been applied, and should be removed through a small sion placed directly over it. The knee should not be widely opened in the manner etimes described, as this causes quite unnecessary damage to the joint. The after-care ows the lines advocated for meniscectomy

If the loose portion of bone in osteochondritis dissecans has not completely separated is still contained within its crater the best line of treatment is open to argument. he area affected is small, say about 1 cm across, probably it is best to remove the ching fragment. If the area is large and occupies, as it sometimes does, up to one ; or more of the condylar articular surface, it is evident that whatever is done the e is likely to have sustained permanent damage, and it may be considered wiser to to make the fragment re-embed itself by drilling it and its bed and by fixing it with a

peg of bone or a small stainless steel pin. There is not as yet, however unanimity of opinion about the value of this procedure, and it should be reserved, at any rate for the present, for the treatment of the larger lesions.

RECURRING SUBLUXATION OF THE PATELLA

This condition gives rise to diagnostic difficulty only if it is forgotten and not deliberately sought. The history is usually quite clear and definite—that "the knee-cap slips round to the outer side of the knee," but the story of locking or of "something slipping" may suggest a lesion of the lateral meniscus. The differential diagnosis is important. The fact that the patella does move farther than normal on to the outer femoral condyle as the knee flexes is easily demonstrated, and often a roughening of the articular surface of the patella can be felt when the patella is moved across the lower end of the femur

Several factors may underly recurring dislocation of the patella such as congenital elevation of the patella, defective development of the external femoral condyle (it is not clear whether this is the cause of the condition or a result of it), and genu valgum. For this last reason the condition occurs much more frequently in girls than in boys. One factor however that is always present is weakness of the vastus medialis, and the condition can, not infrequently be cured by redevelopment of this muscle by regular exercises. If this treatment is not effective, operation is indicated Because of the damage that the articular surface of the patella must have sustained the best treatment is excision of the patella, except in children, in whom some operation designed to realign the patellar tendons and ligament may have a place The best of these is inward transposition of the attachment of the patellar tendon as described by Goldthwaite and Hauser

Transposition of Patellar Tendon. A mid thigh tourniquet is applied. A mid-line longitudinal incision is made from 2 in. above the patella to 1 in below the tibial tuberosity and the flaps are reflected so that the whole of the patella and the patellar tendon are displayed. The quadriceps expansion is incised on each side of the patella and incisions are continued down so that the patellar tendon is defined to its insertion. The incision on the outer side skirts the bone that on the inner side should be made ½ in medial to the patella.

The insertion of the patellar tendon is defined. A block of bone bearing this insertion —usually about ¾ in. square—is cut out of the tibia it is best to cut through the whole thickness of the cortex. The patellar tendon with the attached block of bone is turned up A bed is prepared on the front of the head of the tibia 1 in. medial and about ½ in distal to the original site of insertion, and the block of bone with the patellar tendon attached is fixed in this bed either by jamming it in or by securing it with a screw

The inner incision in the extensor expansion is sutured with overlap so that the inner side of the expansion is reefed the incision on the outer side is allowed to gape. The whole alignment of the extensor insertion is thus shifted medially and outward dislocation of the patella is prevented.

Eight weeks of plaster immobilization is needed and full knee flexion should be regained in 6 to 8 weeks after the plaster is discarded. The practice of regular quadriceps exercises throughout the convalescence and for a long time afterwards is of the highest importance. This is a dependable operation.

Chondromalacia Patellæ

This is in effect a localized degenerative osteoarthritis of the articular surface of the tella and the corresponding surface of the femoral condyle usually the outer The mptoms are those of instability of the knee, felt mostly in going up and down stairs or lls. They resemble those of derangement due to cartilage lesions, but are much less ecise in that they are not localized. The knee does not lock. There is often a slight lusion, and grating of the patella on the femur can be felt when the knee is flexed and tended or when the patella is moved laterally across the lower end of the femur ie lesion is difficult to demonstrate radiologically but it may sometimes be seen in an ial view of the flexed knee which shows the articular surface of the patella in profile. ie only effective treatment is removal of the patella.

Excision of the Patella. The operation is performed with a tourniquet placed high on the thigh because it is desirable to remove the tourniquet before the operation is mpleted it is convenient to use a pneumatic cuff The skin incision is short and is aced transversely across the front of the patella. The skin creases at the knee run insversely and the scar of a transverse wound is much less conspicuous than that of a rtical wound. The expansion of the extensor insertion which passes over the front of e patella is incised and dissected from it with a sharp scalpel as close to the bone as ssible By this means quite a substantial layer of extensor expansion can be preserved ssection is continued all around the bone until it is freed and removed.

Three or four mattress sutures of strong nylon are placed between the rectus tendon d the patellar ligament so that a generous hold is obtained on each. The tourniquet then removed or deflated. The grip of a tourniquet around the thigh anchors the adriceps, and its removal facilitates approximation of the tendon to the ligament. ie ligament is pulled down with tissue forceps until the gap is closed and the mattress tures are tied. The superficial layer of the quadriceps expansion is repaired over the ture line and the medial and lateral expansions are overlapped. If this is done so that e expansion is bunched the resulting projection almost conceals the fact that the tella is absent, a point which, together with the inconspicuous transverse scar may be considerable cosmetic importance to women.

The skin wound is closed, and a pressure bandage and a plaster slab are applied and t till the skin sutures are removed at 10 days. The knee is thereafter splinted in a aster cylinder until 6 weeks from the operation. Quadriceps drill is practised through-it the entire convalescence, and as soon as the plaster cylinder is on, the patient may lk This operation is dependable and, if due attention is paid to detail in the reparative turing, does not leave any disability

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CHAPTER XII

SURGERY OF THE HAND

O J VAUGHAN-JACKSON

TENDONS AND MUSCLES

Tendon surgery represents the pinnacle of all the reconstructive surgery of the hand. The surgery of skin, bone, nerve and ligament, important as each may be, is subservient to the ultimate object of restoring digital and manual dexterity which presents some of the trickiest technical problems in the whole of hand surgery Since the introduction of antibiotics, the risks of surgery have been less and hands devasted by infection are less common. The potentialities of tendon surgery are both wider and clearer cut, and what was regarded twenty years ago as a rather sterile field has been transformed into one of great promise.

Tendon Injuries

Tendon injuries comprise traumatic divisions (tidy or untidy), avulsions, ruptures (spontaneous or due to attrition) contusions and burns. To take these in the reverse order *burned tendons* present no special problem qua burn. After skin loss has been made good we are left with the problem of a scarred area and loss, or binding down, of tendons. Grafts or transfers, will commonly be needed and primary or secondary suture will rarely be possible.

Contusions commonly cause only temporary trouble but may result in adherence of tendons, especially of the flexors within their digital sheaths, enough, perhaps to demand a tenolysis or even replacement by a suitable graft. It should be remembered that a tendon pinched between a hard striking object and a hard underlying bone may be divided as cleanly as if by a knife, without there being, necessarily any worse skin damage than a bruise.

Attrition ruptures are of peculiar interest and are commoner than is usually supposed. Rupture of extensor pollicis longus, by attrition over a roughened lower end of radius following a Colles fracture, is a condition described in all the books, but it cannot be said to be common. Attrition rupture of the common extensor tendons at the inferior radio-ulnar joint was not described in the literature in English for 30 years up to 1948. Since then, without any particular search, 21 personal cases and nine others are known to the writer It is clear that the condition is quite common but has been missed, probably because it is associated particularly with rheumatoid arthritis. Flexed metacarpo-phalangeal joints, with ulnar deviation of the digits, are so common in this condition that the deformity is attributed without further thought, to the arthritis. But a pattern of attrition so complete that a detailed prediction of the operative findings can be confidently made has now been seen often enough to make it certain that a significant proportion of these deformities are caused, in part at any rate, by such attrition ruptures.

The rupture is usually painless which explains how it may pass unnoticed by a patient pre-occupied with many painful joints. Where it is noticed the usual history is, first, of

Chondromalacia Patellae

This is in effect a localized degenerative osteoarthritis of the articular surface of the patella and the corresponding surface of the femoral condyle usually the outer The symptoms are those of instability of the knee, felt mostly in going up and down stairs or hills. They resemble those of derangement due to cartilage lesions, but are much less precise in that they are not localized. The knee does not lock. There is often a slight effusion, and grating of the patella on the femur can be felt when the knee is flexed and extended or when the patella is moved laterally across the lower end of the femur. The lesion is difficult to demonstrate radiologically but it may sometimes be seen in an axial view of the flexed knee which shows the articular surface of the patella in profile. The only effective treatment is removal of the patella.

Excision of the Patella The operation is performed with a tourniquet placed high on the thigh because it is desirable to remove the tourniquet before the operation is completed it is convenient to use a pneumatic cuff The skin incision is short and is placed transversely across the front of the patella. The skin creases at the knee run transversely and the scar of a transverse wound is much less conspicuous than that of a vertical wound The expansion of the extensor insertion which passes over the front of the patella is incised and dissected from it with a sharp scalpel as close to the bone as possible By this means quite a substantial layer of extensor expansion can be preserved. Dissection is continued all around the bone until it is freed and removed.

Three or four mattress sutures of strong nylon are placed between the rectus tendon and the patellar ligament so that a generous hold is obtained on each. The tourniquet is then removed or deflated. The grip of a tourniquet around the thigh anchors the quadriceps and its removal facilitates approximation of the tendon to the ligament. The ligament is pulled down with tissue forceps until the gap is closed and the mattress sutures are tied. The superficial layer of the quadriceps expansion is repaired over the suture line and the medial and lateral expansions are overlapped. If this is done so that the expansion is bunched the resulting projection almost conceals the fact that the patella is absent, a point which, together with the inconspicuous transverse scar may be of considerable cosmetic importance to women.

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CHAPTER XIV

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TENDONS AND MUSCLES

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The rupture is usually painless which explains how it may pass unnoticed by a patient pre-occupied with many painful joints. Where it is noticed the usual history is, first, of

an abrupt painless inability to extend the little finger After an interval, perhaps only of a week or so, the ring finger abruptly follows suit If the patient does not then seek aid the middle finger will also follow suit in due course. The loss of extension is at the metacarpo-phalangeal joint, the intrinsics still extending the interphalangeal joints. The extensor tendons to the affected fingers cannot be seen in normal tension on the dorsum of the hand (*Fig. 249*) where instead their thickened distal ends may be palpable

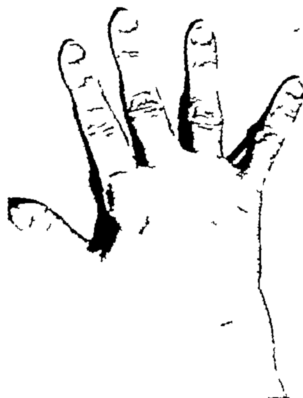




Fig. 250. Radiograph of the hand in Fig 1. The lower end of the ulna is markedly eroded by Rheumatoid Arthritis

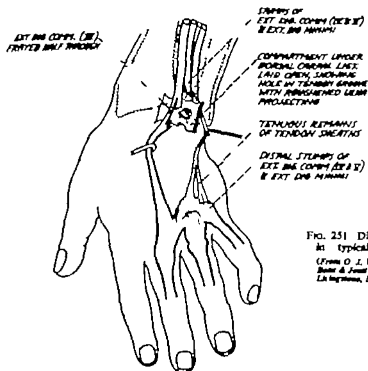


Fig. 251 Diagram of operative findings in typical case.

(From O. J. Vaughan-Jackson, Journal of Bone & Joint Surgery 30B, E. & S. Livingstone, Ltd.)

in flexion and extension, and of the spicule across the tendon margin in pronation and supination.

While, in Active Rheumatoid Arthritis, tendons *may* undergo occasional spontaneous degenerative rupture the easy assumption that this is always or even usually the cause in these cases is put right out of court by the constant complaint of ruptures *seriatim*, always starting on the ulnar side and working towards the radial, by the constant finding of the abrasive spicule and by the finding of partial severance of *normal* tendons.

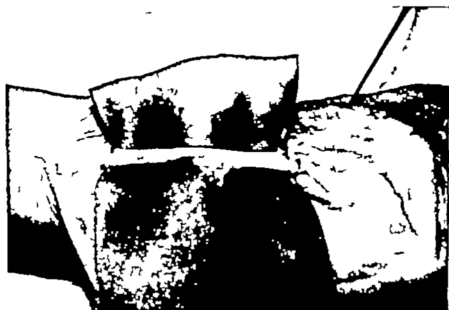


FIG. 252 Normal tendon of Extensor Communis Digitorum to the middle finger abraded half way through, by the roughened ulna, after the tendons to ring and little fingers had been severed (same case as in Fig 1)

Simple excision of the offending lower end of ulna and individual tendon grafts to the severed tendons can restore full normal function so recognition of this fact may yet alter the prognosis of the Rheumatoid hand significantly The simpler procedure of "cobbling" the distal ends of the severed tendons to the nearest intact extensor to form a "common" extensor works badly probably because the line of pull is altered enough to reduce materially the effective excursion of the damaged tendons.

Similar attrition ruptures occur in the flexors at the wrist where the abrading agent may be a spicule of bone lying point forward after a Colles fracture or roughened bone due to Rheumatoid arthritis, or even a Kienböck s disease. In all these ruptured tendons the paratenon was drawn out into a thickened opaque greyish strand between the tendon ends, which were not easily discernible in it as such until dissected out (Fig. 253).

Avulsion Injuries of Tendons

Mallet Finger This is generally an avulsion injury of the attachment of the extensor tendon to the base of the distal phalanx, caused by sudden forced flexion of the unguarded

distal joint by such things as a football striking the finger tip end on. Cuts on the dorsum of the joint can divide the tendon and cause the same deformity These are best treated by primary suture and the results are better than in avulsion injuries.

In a fresh closed injury simple immobilization of the finger in plaster with the distal joint hyperextended and the proximal interphalangeal joint fully flexed, to bring the lateral bands of the extensor distally and so permit the ruptured ends to meet, is said usually to be sufficient though this may be doubted It all depends on how prompt is



FIG 253 Attrition rupture of Flexors Profundus and Sublimis to the little finger The opaque strand uniting the tendon ends, so often called a "stretched degenerate tendon" is held up on the hook and is clearly seen to be, in fact, a tube of paratenon. The proximal tendon stump peeps out, the distal is indicated by the probe.

treatment. The proximal end very soon adheres so that apposition in this manner is impossible.

In old cases scar tissue has bridged an actual gap and the tendon ends cannot be apposed. Nothing but an open repair can cure and actually by whatever method, the results are rather uncertain. As an uncorrected mallet finger rarely involves any disability except the cosmetic defect, open procedures are of debatable value. When a repair is decided upon the use of a thin length of palmaris longus passed through a hole drilled laterally through the base of the phalanx, turned towards the dorsum, and from there criss-crossed into and through the extensor tendon (Fig. 254 (*a*)) is as good as any

When there is an avulsion fracture of the dorsal lip of the articular surface of the phalanx the indications for exploration are stronger Such fragments, if small, can cause tenderness and are possibly better removed, the opportunity being taken to repair the insertion If large, forward subluxation of the phalanx is prone to occur Malunion and secondary arthritic changes will follow Open reduction and securing the fragment

in flexion and extension, and of the spicule across the tendon margin in pronation and supination.

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Fig. 255 (a). Boutonnière Deformity of middle finger

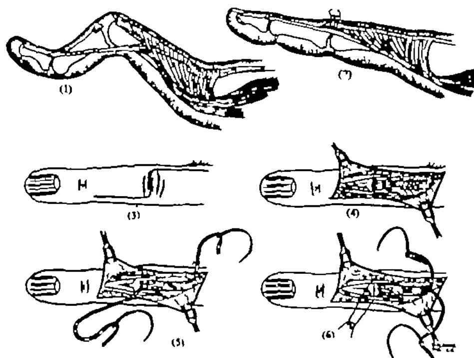


Fig. 255 (b) (1) Pathological anatomy of the deformity and method of repair (2) of the fresh injury and (3), (4), (5), (6) of the older injury using fine tendon graft.

with a wire suture offers the best prognosis (Fig. 254 (*b*)) However this injury is treated the patient should be warned that some loss of extension of the distal joint is practically inevitable.

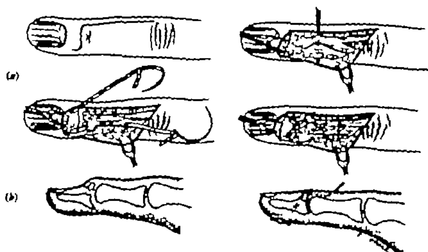


Fig. 254 (*a*). The extensor tendon is mobilised from scar tissue over the dorsum of the terminal interphalangeal joint, the scar excised and the gap repaired by a criss-cross graft.

Fig. 254 (*b*). A method of securing an avulsed bone fragment by withdrawable wire suture. The possibility of infection of wire tracks so close to joint needs bearing in mind, and a *non-withdrawable suture may be preferred.*

Avulsion of Extensor from Middle Phalanx

The extensor mechanism, over the dorsum of the proximal interphalangeal joint, is relatively tenuous and vulnerable. If its attachment to the base of the middle phalanx is ruptured the two lateral bands tend to slide down over the sides of the joint until, being over dead centre they become flexors of the proximal joint while remaining extensors of the distal, producing *the characteristic disability of hyperextension of the distal* joint with inability to extend the flexed proximal joint (Boutonnière Deformity) (Fig. 255 (*a* and *b*)) Repair is not easy primary suture of the tenuous attachment often fails and the central slip may have to be replaced by *a short graft* *Some loss of movement* is to be expected (Fig. 255 (*b*)).

Division of Tendons

A divided tendon can be repaired by

(*a*) Suture, (i) primary
(ii) secondary

(*b*) By replacement, with a graft.

(c) By substitution *of another tendon*

(*d*) Occasionally by advancement or lengthening.

Methods. The aim here is to select and simplify and a certain knowledge of detailed suture techniques is assumed but some general aspects must be considered.

Unquestionably these methods work and the risk of infection of the wire tracks is doubtless very small in careful hands. Nevertheless risks mount with every elaboration and it seems clear at least as far as major tendons are concerned, that modern wire sutures are so inert that the only elaboration that is really *necessary* is the placing of sutures predominantly within the substance of the tendon, allowing them to emerge on

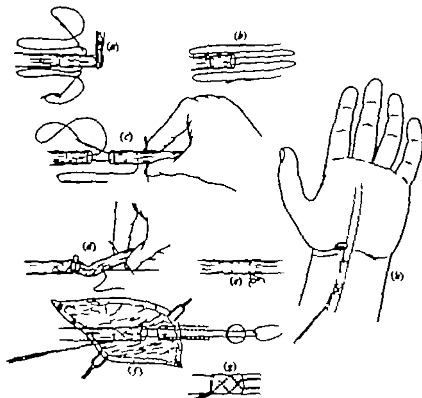


FIG. 257 (*a* and *b*). Method of using double ended fine wire suture, the ends emerging at the cut face of the tendon.

FIG. 257 (*c* *d*, and). The two needles enter the cut face of the distal tendon stump. A round bodied needle transfixing the latter enables it to be held conveniently so as to relax tension while the suture is drawn tight.

FIG. 257 (*f* and *g*). In the withdrawable suture a withdrawal wire is looped through the suture. The two ends of the suture are not criss crossed in the distal stump but taken straight through it and out to the surface where they are tied over a button. After withdrawal no suture material is left at the junction.

FIG. 257 (*h*) A withdrawable suture, in the proximal stump only holds it distally against its tendency to retract so that minimal suturing suffices to hold the tendon ends together though these sutures remain permanently

the surface to a minute extent only The results are no worse than when the suture has been removed. The choice is a matter of personal preference.

When attaching tendon to bone, especially in the digits, it is perfectly reasonable to lift up osteo-periosteal trap doors, or to thread the tendon through holes in the bone so that the tendon can get firm attachment to bone. But here the addition of removable sutures is much more questionable. In the repair of a mallet finger or the attachment to the distal phalanx of a graft replacing the profundus, sutures emerging on the surface of

The basic aim of a tendon suture is the restoration of normal or nearly normal mobility It is obvious that a good range of passive mobility in the joints moved by the tendon is an essential prerequisite yet cases are still presented for operation where joint stiffness dooms any repair to failure before it is begun.

The next aim is a strong union. It is little use suturing scar to tendon or scar to scar What is needed is the accurate tensionless apposition of clean cut *tendon* ends. Tension makes for separation and scarring. The trimming of tendon ends to fit each other needs no comment where the tendons are of comparable size. But with grafts or substitutions the apposed ends may be very different in size and there must be no "unsatisfied" bare tendon end exposed after the suture is completed or it will eventually adhere to its surroundings. Indeed a disparity in size is often recommended on the grounds that a tendon

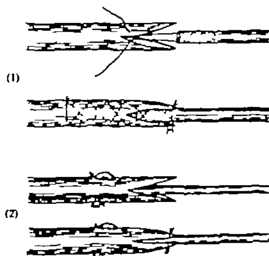


FIG. 256 (1 and 2). Two methods of joining tendons of unequal size.

of the size, say of palmaris longus will be free in the narrowest straits of a flexor tendon repair under the conditions of post operative swelling when a thicker graft would adhere firmly at points of pressure. A convenient method of overcoming this disparity is to cut a "V" in the thicker end and insert the thinner in the "fishmouth" so formed (Fig. 256).

Next, adherent suture lines may be due to unsuitable suture material. Catgut, silk and the like produce far too much local reaction to be acceptable and a thin inert monofilament is essential. Very fine stainless steel or tantalum wire is sufficient for the purpose and provokes minimal reaction. Results with these materials are very satisfactory Notwithstanding this some pin their faith to the suture which is not there at all, as provoking least reaction that is to say a wire suture that can be removed (Bunnell). *This consideration led to elaborate techniques of suturing to enable a separate withdrawal* suture to extract the "apposition" suture, after an interval, when the tendon has united. But the ends of both sutures must emerge on the surface and the apposition suture must be made fast at the surface to a button or something similar Such a suture placed proximally and emerging distally can hold the tendon ends in apposition against the tendency of the proximal end to retract, without there being any sutures at all, in the ordinary sense, at the junction ("Suture at a distance"—Bunnell) (Fig. 257 (*a* to *h*)).

as the pull on recently explored tissues merely inflames and irritates them thickening, fibrosis, and adhesions are certain. For every case that gets away with good mobility in this manner there will be several that do not The spectacle of stiff fingers after three weeks post-operative immobilization may be daunting but patience and perseverance seldom fail to bring their reward.

With any divided tendon then, primary or early secondary repair is the ideal It may be ruled out by contamination in an untidy wound, but even here antibiotics and improved techniques in securing immediate skin cover have increased the possibilities in this direction.



FIG 258. Flexor tendon repair by Palmaris longus graft in the little finger The fibrous flexor sheath has been completely removed except for two bridges to prevent "bowstringing" of the graft.

Problems in Relation to the Site of Repair

(1) IN THE DIGITAL SHEATHS primary or secondary suture is unfortunately always ruled out in the flexors of the fingers at any level between the metacarpo-phalangeal joint and the proximal interphalangeal joint. Some would include the whole length of the flexor tendons in the finger in this prohibition. In other situations the tendon suture line, though it inevitably adheres to its surroundings to some extent, will remain mobile if these tissues are themselves mobile. In the rigidly fixed flexor sheath in the fingers no such compensatory movement is possible and adhesions fix the repaired tendon absolutely If the sheath is excised adherence will be to the subcutaneous tissue and greater mobility is possible In children, with the greater adaptability of their tissues, this may suffice, but in adults the excellent results of tendon grafting make it unnecessary to accept the high failure rate of primary suture. With a graft the suture lines are in situations where they may safely adhere.

The presence of two tendons in the no mans land of the flexor sheath complicates the issue still further

If both tendons are divided the best results follow excision of the sublimus and repair of the profundus by a free graft.

If the profundus alone is divided it occasionally causes negligible disability and can be left. Alternatively a simple method is to restore a stable pinch by arthrodesing the

the finger tip or through holes drilled in the fingernail bring a portal of entry for sepsis far too close to the distal joint for us to contemplate it with any equanimity The object of both repairs is to regain *movement* at the distal joint and this object is better served if the sutures remain buried. The merest "whiff" of infection in this situation will effectively limit movement in the joint.

Moreover with the profundus it is very seldom that the distal stump is so short that it cannot be elevated sufficiently from the phalanx to permit a perfectly good graft-to-tendon suture at a point just as far beyond the joint as is the usual hole bored in the phalanx for a graft-to-bone fixation. While loss of a few degrees of extension may be of little importance a similar loss of flexion is quite another matter especially in the ring and little fingers. Here loss of the last few degrees of flexion can spoil significantly the ability to grip objects of small diameter such as a cord.

Sutures of tendons divided in the palm, or of the proximal end of a profundus graft, are carried out in the same manner as described. However in the latter case it is usually possible to cover the suture line by suturing the lumbrical loosely over it.

Tendon Grafts

A few points about free tendon grafting are worth special mention. The graft most commonly performed is the replacement of both flexors in the finger by a single graft of palmaris longus, plantaris, or a toe extensor In taking the graft a full length incision is necessary so that the mobile paratenon can be taken with the tendon. If the tendon is stripped out through an incision at each end this essential aid to future mobility is left behind. In this connection the use is sometimes advocated of free grafts" of mobile fascia from, say the forearm or the region of the insertion of the triceps, to cover scarred areas or bare bone on which a tendon graft will have to lie Opinions on this vary Certainly it can succeed but also tendon grafts regularly succeed without it. It seems reasonable to use this method if there is an extensive area of scar or raw bone to which the graft might adhere

The treatment of the flexor tendon sheath is widely agreed to-day Attempts to preserve or repair it regularly result in adherence of tendon, or graft, to it. The removal of all but two narrow "bridges" over the proximal and middle phalanges (under which the graft is threaded so that it shall not bowstring), regularly results in a satisfactorily mobile graft (Fig. 258).

The question of tension in the sutured or grafted tendon is important. If there is loss of tendon substance end to end suture must produce a degree of contracture which may be unacceptable If the contracture cannot be corrected by an appropriate lengthening of the tendon somewhere in its length, it must be avoided by using a free graft, or transposing some other tendon that can be spared. Whatever is done the final tension should allow the hand and fingers, when released, to lie in their usual relaxed "position of function" Possibly a shade tighter in the repaired tendon may be accepted to allow for stretch during the healing period. Since the joints involved have to be immobilized for three weeks the tendon repair *must* lie under minimal tension with the joints lying comfortably somewhere in their middle range

Experience shows that sutured tendons are not strong enough to sustain tension without stretching in under three weeks. For this reason alone early attempts at mobilization are in general undesirable. Very early (next day) mobilization is highly undesirable

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The presence of two tendons in the no mans land of the flexor sheath complicates the issue still further

If both tendons are divided the best results follow excision of the sublimus and repair of the profundus by a *free graft.*

If the profundus alone is divided, it occasionally causes negligible disability and can be left. Alternatively a simple method is to restore a stable pinch by arthrodesing the

mobile. When the flexor profundus acts the origin moves proximally and the lumbrical, unless it actively relaxes, helps to stabilize the metacarpo-phalangeal joint in some flexion while the profundus flexes the interphalangeal joints. Were this not so the profundus would flex the interphalangeal joints while being unable to prevent extension of the metacarpo-phalangeal joint. This is the clawed position of the fingers seen when "the intrinsics" are paralysed. The volar interossei contribute a little to this effect, the dorsal interossei practically not at all.

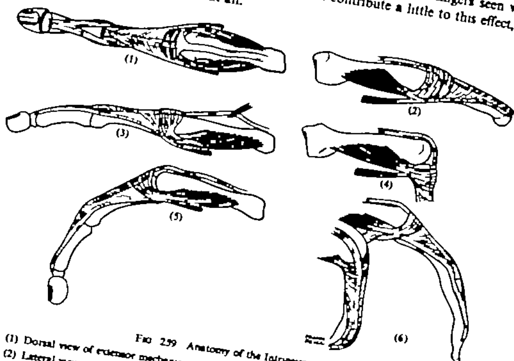


FIG. 259. Anatomy of the Intrinsics.

(1) Dorsal view of extensor mechanism.
(2) Lateral view.
(3) With the transverse fibred "hood" pulled proximally over the metacarpo-phalangeal joint the intrinsics exert full extensor power through the lateral bands.
(4), (5), (6) The more the hood is pulled distally over the base of the proximal phalanx the more do the intrinsics act as flexors of the metacarpo-phalangeal joint, and the less as extensors of the interphalangeal joints.

This stabilizing action of the lumbrical is perverted when the profundus is divided distal to the lumbrical origin. Even if the power of the retracted profundus is diminished it comes fully on the lumbrical alone, the increased tension in which will either partly flex the metacarpo-phalangeal joint or prevent flexion of the inter phalangeal joints or both. Loss of flexion after division of the profundus may thus have a double cause. Full success of a graft replacement of a profundus depends upon a length of graft being chosen that restores the lumbrical origin to its proper position.

It is clear that the number of possible combinations and permutations of contraction, inaction or relaxation of these fascinating muscles in modifying the basic actions of flexors and extensors, is astronomical. The term "intrinsic imbalance" is by no means just an escapist expression to cover our ignorance. That we are still too ignorant of

intrinsic function underlines the fact that intrinsic balance is a very real and important thing, worthy of much more of our attention than it has hitherto received. Solid success has attended our efforts with the large tendons of the hand. The triumphs of hand surgery in restoring manipulative dexterity will come when we can replace lost intrinsic function with certainty How far have we got along this road?

Dysfunction of Intrinsics

Flexor-extensor balance in the fingers can be upset in the direction of either too little or too much intrinsic action, or as Bunnell termed them, the "Intrinsics minus" and "Intrinsics plus" conditions.

(1) "INTRINSICS MINUS." This condition is comparatively rarely found as a result of actual division of intrinsic muscles or tendons except in the case of wounds of the thumb web and radial aspect of the index metacarpal and metacarpo-phalangeal joint, when it is strictly localized. The usual cause is paralysis resulting from ulnar or median or combined ulnar and median nerve lesions, with resulting clawing of the fingers. The most significant loss is the extensor action through the lateral bands, the lost abduction and adduction at the metacarpo-phalangeal joints being less important except in the index where abduction is an important component of stabilization of the index in pinching. Clearly the best answer to this is a successful nerve repair but recovery takes time in any case, we have to be prepared for failure, and while the issue is being decided the clawing can become fixed if it is not corrected. It only requires a Knuckle-duster" splint preventing hyperextension at the metacarpo-phalangeal joint to restore nearly normal flexor-extensor balance. The hand can be used effectively and normal joint mobility maintained. In a combined median and ulnar lesion the thenar muscles are also affected and the restoration of adduction and, particularly opposition present a special problem. While awaiting nerve recovery an opponens element is added to the splint to keep the thumb from falling back into a useless position in the plane of the palm.

In the case of irrecoverable nerve injury the only alternative to continued use of a splint is an attempt to substitute active muscles for the paralysed intrinsics. Bunnell first tackled the problem by using the sublimis tendons. The requisite number of sublimis tendons are detached from their insertions through mid lateral incisions in the fingers. Each is then withdrawn into the palm and split proximally from the detached end into two or more thin slips. These are then passed distally through the lumbrical canals and attached to the extensor hoods at the lumbrical insertions.

These sublimis transplants can be extremely successful but they have been found to have two disadvantages. First, in long standing clawing, the habit of flexing the wrist when trying to extend the fingers is so strong that it is usually persistent and, such flexion relaxes the sublimes. Second they cannot be used if the sublimes are weak or paralysed.

Fowlers use of the proper extensors of index and little fingers, re routing them through the interosseous space and through the lumbrical canal before attaching them to the dorsal aponeurosis, is satisfactory for three reasons. First the proper extensors exert slight extensor action through the lateral bands. But second, their attachment is de liberately made to limit extension at the metacarpo-phalangeal joint to just short of 180° This, as we have seen, allows the common extensors to extend the interphalangeal joints. Third, the attachment to some extent limits palmar flexion at the wrist. The operation is then in its essentials, a tenodesis (Fig. 260 (3 and 4))

structures. Be that as it may considerable advances have followed clear recognition of the problem

Fibrosis may result from thermal or mechanical injuries or inflammation. Naturally it tends to be more localized or patchy in its incidence than after an ischaemia of the whole hand and we may have intrinsic contracture affecting, say only one finger

Long continued spasm will result in fibrosis of the affected muscles and the Rheumatoid hand presents a common example of such a contracture Harris and Riordan have described the same condition in Leprosy where the process attacks the nerve slowly

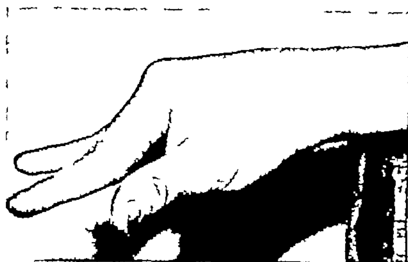


Fig 262 Intrinsic Plus position of the hand

producing an irritative spasm for some time before the nerve is finally knocked out. When the process is more rapid paralysis is early and an "intrinsic minus" condition develops.

The results of this contracture are what one would expect. Contracture of the finger intrinsics produces a flexion of the metacarpo-phalangeal joints and extension of the interphalangeal joints (Fig. 262) *The fingers are held stiffly extended throughout the range of movement of the metacarpo-phalangeal joints which may be itself restricted.* Only when these joints are fully flexed to 90 can flexion take place at the interphalangeal joints (and not then if generalized fibrosis of the tissues is too extensive). This fact provides us with a reliable test for this contracture. If the metacarpo-phalangeal joints are held fully extended passively pressure on the finger nail will be resisted through the tautness of the lateral bands and flexion of the finger will not be possible. The normal range of movement of the intrinsics is divided between their interphalangeal extensor function and their metacarpo-phalangeal flexor function If all of a restricted intrinsic range is used up by *keeping the metacarpo-phalangeal joints extended none is left* to permit flexion of the interphalangeal joints (Fig. 263 (*a* and *b*)).

The clinical picture is completed by the contracture of thenar and hypothenar muscles. The thumb is adducted into the palm, flexed at its metacarpo-phalangeal joint and

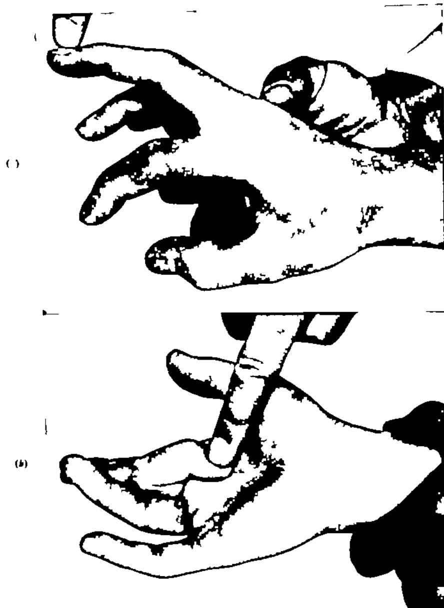


FIG. 263 (*a*). Contracture of the Intrinsics. If the metacarpo-phalangeal joint is held extended passively the tight intrinsics prevent passive flexion of the interphalangeal joints.

FIG. 263 (*b*). If the metacarpo-phalangeal joint is allowed to bend the intrinsics are relaxed and the interphalangeal joints can be flexed.

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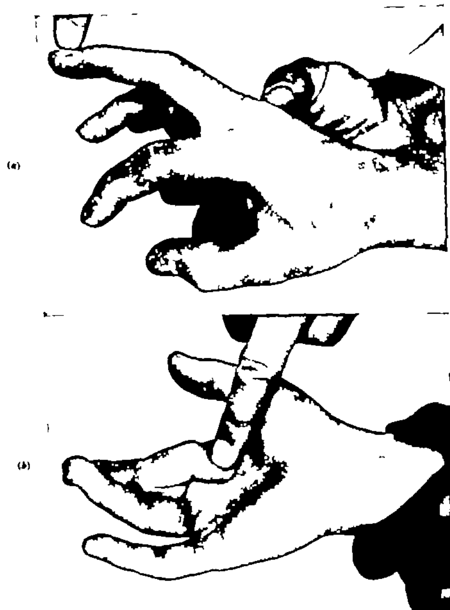


FIG. 263 (a) Contracture of the Intrinsics. If the metacarpo-phalangeal joint is held extended passively the tight intrinsics prevent passive flexion of the interphalangeal joints.

FIG. 263 (b). If the metacarpo-phalangeal joint is allowed to bend the intrinsics are relaxed and the interphalangeal joints can be flexed.

hyperextended at its interphalangeal joint. The hypothenar muscles are contracted and the metacarpal arch of the palm exaggerated (Fig. 262)

Bunnell first attacked the problem by a dorsal exposure of the interossei and stripping them from their origins on the metacarpals while preserving their nerve supply. This allowed them to retreat distally and the hand was put up in the overcorrected (claw-hand) position until they had become reattached more distally. A pre requisite is that the muscles should be working, for clearly if they had been destroyed by fibrosis teno-tomy would be a less traumatic procedure. Although this method results in improvement

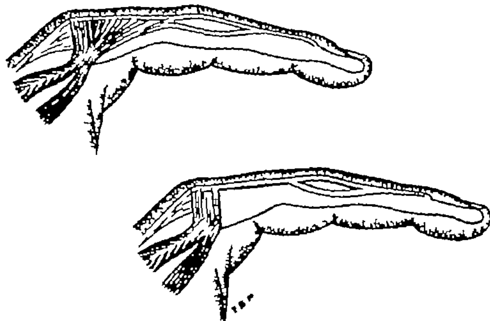


FIG. 264 Release of Intrinsic Contracture to permit finger flexion (Littler).

it is objected to on the grounds that it is too traumatizing, the hand has to be immobilized in an extreme position far removed from the position of function, and the results are unreliable.

Bunnell's second string in case of failure with the stripping procedure was a simple tenotomy of the lateral bands. This sometimes resulted in temporary improvement followed by reversion. Littler has developed this attack and releases the extensor component of the intrinsics while preserving their metacarpo-phalangeal flexor component. The dorsal aponeurosis is approached through a dorsal mid line incision giving access to both sides of the digit. The oblique fibres (lateral bands) are excised as shown (Fig. 264) and the transverse fibres carefully preserved. Great care is necessary so as to remove enough but not too much. The oblique fibres are freed from the long extensor but not separated from the transverse fibres until the following test has been applied. The metacarpo-phalangeal joint is held extended. If the interphalangeal joints will not flex the clearance has not come far enough proximally. If the metacarpo-phalangeal joint will not hyperextend and the interphalangeal joints will flex, exactly the right amount has been cleared. If the metacarpo-phalangeal joint will hyperextend as well as the

interphalangeal joints flexing, the clearance has come too far proximally and the intrinsics insertion must be re-sutured to a point where hyperextension cannot occur. The redundancy is then removed. If hyperextension of the metacarpo-phalangeal joint is permitted we have simply substituted a claw hand for an intrinsic contracture.

In after treatment the hand is placed on a palmar plaster splint extending along the forearm and as far distally as the middle of the proximal phalanx. This permits active movement at the interphalangeal joints while immobilizing the disturbed area of the metacarpo-phalangeal joint and dorsal aponeurosis. After about 14 days the plaster is replaced by a "lively" knuckle bender splint and full remobilization exercises are carried out.

The Muscles of the Thenar and Hypo-thenar Eminence

Anatomy and Function. A very similar type of extensor arrangement with a dorsal hood is present in the thumb. Attached to its lateral bands are Abductor Pollicis Brevis and a slip from Flexor Pollicis Brevis on the radial side and a slip from the adductor on the ulnar side. These muscles are, then, extensors of the interphalangeal joint as well as flexors of the metacarpo-phalangeal joint. The only other important detail to remember is the rolling action of the two opponens muscles (especially opponens pollicis which brings the thumb metacarpal round to face the others) which serves in general to accentuate the metacarpal arch and cup the hand.

Dysfunction of the Thenar and Hypo-thenar Muscles

(1) Intrinsics Minus. The ulnar and median nerve territories overlap variably in the hand, so the results of palsies of these nerves are not quite constant. However assuming the classical distribution, in a complete ulnar nerve lesion it is clear that the hypo-thenar muscles will *all* be paralysed resulting in a loss of abduction of the little finger, of flexion of its metacarpo-phalangeal joint, and of opposition. Clawing of the finger and flattening of the ulnar half of the metacarpal arch results.

In addition, in the thenar eminence, the adductor and the deep head of the flexor pollicis brevis are paralysed. As well as the obvious wasting of the thumb web this produces a characteristic disturbance of pinch between thumb and index. In a normal pinch the thumb and index form an O which requires stabilization of the thumb carpo-metacarpal joint in abduction by the abductor pollicis longus, stabilization of the metacarpo-phalangeal joint in flexion, by the flexor pollicis brevis (ulnar nerve) and stabilization of the index metacarpo-phalangeal joint, against adduction, by the first dorsal interosseus (ulnar nerve). Paralysis of the short flexor results in extension at the metacarpo-phalangeal joint which is compensated for by greater flexion of the inter phalangeal joint by the long flexor. This is the basis of Froment's test.

The motor disturbance in the thumb in a low median nerve lesion is partial, for adduction is preserved. Half of the short flexor remains to flex the metacarpo-phalangeal joint and assist in extension of the inter phalangeal joint. The short abductor is gone but the long remains. Only the loss of opposition is complete. The radial half of the metacarpal arch is weakened and flattened.

In combined ulnar and median nerve palsy the ape hand is seen with clawing and loss of abduction and adduction of all the fingers; the metacarpal arch is destroyed and the thumb lies useless beside the flattened palm.

(2) INTRINSICS PLUS. In this condition the opposite obtains the metacarpal arch is exaggerated by both opponens muscles and the adductor and the thumb is held into the palm with metacarpo-phalangeal joint flexed and interphalangeal joint extended.

Consideration of Ulnar and Median nerve palsies only covers part of the picture. The same functional disabilities may be produced by scars or joint deformities which pose a separate problem. Here we are considering only the primary condition in the intrinsics muscles themselves.

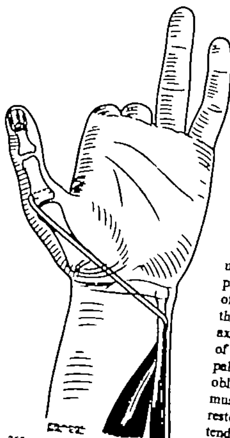


FIG. 265. Method of restoring opposition to the thumb using a flexor tendon

Treatment of "Intrinsics Minus" in the Thumb. In the "minus" condition there are two interrelated factors to consider. First there is opposition of the thumb. But the complement of this is opposition of the rest of the hand, or more simply arching of the metacarpal plane to achieve convergence of the finger tips towards the thumb. There are accordingly two groups of operations for these two objectives.

Opposition of the Thumb

Many different tendon transfers have been used to restore opposition: an abundance of procedures is often testimony to the inadequacy of most of them and Bunnell's clarification of the essential principles has been salutary. It is axiomatic that to restore the cross palm element of opposition the tendon must pull across the palm—towards the pisiform, and not, even obliquely up the forearm in the line of the long muscles. It seems equally axiomatic that to restore the rolling element of opposition the tendon must pass across the dorsum of the thumb to be inserted somewhere on its ulnar side. If it is further realized that to attach the tendon much beyond the metacarpo-phalangeal joint can only result in flexion of that joint and not in opposition of the thumb the essentials of the operation are inescapable. One of the long tendons, usually flexor sublimis to the ring finger is detached and brought proximally into the forearm and re-routed either through a pulley constructed of a loop of tendon at the pisiform or more simply passed under the tendon of flexor carpi ulnaris near its insertion and turned sharply around its ulnar margin to pass from this point subcutaneously to the metacarpo-phalangeal joint of the thumb. It is passed across the dorsum of this joint (no further distally) and inserted into the ulnar side of the base of the proximal phalanx under such tension that the thumb, with the rest of the hand, lies in the normal position of function of the relaxed hand (Fig. 265). However Riordan has found that if the sublimis is attached to the tendon of abductor pollicis brevis, and a slip taken beyond this into the tendon of extensor pollicis longus, equally good opposition is obtained (the rolling component of

the movement seems to be taken care of by the shape of the articular surfaces of the carpo-metacarpal joint of the thumb) But more important extension of the terminal phalanx of the thumb, which is usually weakened by the paralysis which makes the operation necessary is strengthened as well.

There is no more rewarding operation. It always seem to work well and quickly The sublimis is of the right length and no free grafts are necessary If sublimis is not available other motors are feasible, e.g. flexor carpi ulnaris or palmaris longus, but these are too short and must be lengthened with a free graft.

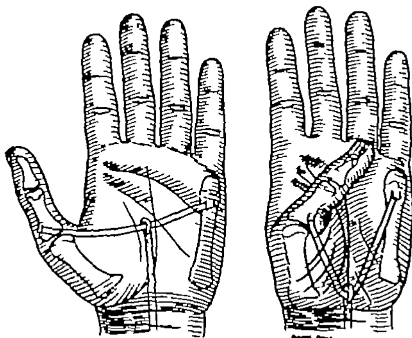


FIG. 266. Principle of Bunnell's Tendon T operation.

Usually this repair is enough and for example, in the common selective "knock out" of the thenar muscles in poliomyelitis, the patient is very well pleased But in the mutilated hand where, say index and middle fingers are missing, the necessity for the thumb to reach the ring or little finger tips immeasurably increases the importance of being able to arch the metacarpals (Fig. 265)

Restoring Metacarpal Arch

This will demand a procedure such as Bunnell's tendon T operation. In this a free tendon graft is attached to the ulnar aspect of the neck of the fifth metacarpal. It is passed across the front of the bone and across the palm behind the flexors to the base of the proximal phalanx of the thumb Here it can be attached to the ulnar side of the base of the phalanx or to the radial side. In the latter event it adds a slight rolling or opposing component. A long flexor (say sublimis to the ring finger) is looped around the graft and sutured to itself When this muscle contracts it pulls the T into a Y bringing the radial and ulnar borders of the palm nearer to each other (Fig. 266)

Treatment of Intrinsics Plus in the Thumb. In this condition in the thumb it is in theory possible to detach the attachments of the first Dorsal Interosseous and the adductor of the thumb and permit them to slide to a new attachment in the corrected position of opposition. In practice it is rarely possible. Usually the thumb is tightly adducted by a fibrotic mass of muscle in the web. To excise this mass the web is split from the base of the first metacarpal on the dorsum to the base of the thenar eminence in the palm. This opens out when the fibrotic muscle is excised leaving a diamond shaped gap which requires an abdominal pedicle graft to cover and fill it. The thumb metacarpal is held in the position of opposition by a bone graft uniting it to the second metacarpal. It may be necessary in order to stabilize the thumb for pinching, to arthrodese the carpo-metacarpal and metacarpo-phalangeal joints of the thumb as well.

Volkmann's Ischaemic Contracture

In 1872 Richard von Volkmann first described an acute post-traumatic muscle contracture in the forearm due to arterial obstruction. Venous occlusion by constricting



FIG. 267. Incidence of forearm muscle necrosis in a typical case of Volkmann's Contracture. The density of the shading indicates the degree of necrosis. Deep flexors, superficial flexors, deep extensors and superficial extensors are affected in that order of severity.

bandages was, and still is, blamed but cases occur without any such constriction. Moreover the microscope shows that the muscle fibrosis produced experimentally by venous occlusion is a perifibrillar fibrosis whereas after arterial occlusion there is a muscle infarct, surrounded by an area of fibrosis around and between surviving muscle fibres. Though the effect on muscle is the most striking all tissues suffer and in the typical contracture an ellipsoid mass of necrotic forearm tissues centred on the anterior interosseous artery includes nerves (medial, ulnar and radial in that order of frequency) and bone (Fig. 267). Nerve palsies are a part and not, as some hold, the cause of the condition.

Arterial occlusion from any cause can produce the condition but it usually follows injury in which the brachial artery goes into spasm. Not uncommonly the vessel is actually nipped between the fragments of a fractured lower humeral shaft.

Clinically pain in the affected muscles, increased if the muscles are stretched by straightening the fingers, is the first symptom It is important to remember it may be masked during recovery from an anæsthetic and the significance of restlessness and crying may be missed in small children

But before the typical pain develops the alert attendant should have spotted loss, or feebleness of the radial pulse. Pulselessness is the important one of the quartet, "Pain, pallor pulselessness and paralysis." To wait for the certainty that accompanies the development of all four is to make certain of one thing only—disaster In addition, swelling, blotchy erythema of the skin, and tenderness are pointers, so splints and dressings after injuries in the elbow region should always permit inspection.

In the fully developed stage of contracture fibrosis of the affected muscles (flexors more than extensors) causes flexion of the fingers that can only be passively corrected with the wrist flexed. In severe cases fibrosis of all structures may modify this by causing adherence of tendons and joint stiffness Paralysis and sensory change vary according to the distribution of nerve damage and follow no nerve territory with accuracy The motor changes are always worse than the sensory The forearm muscles exhibit a bunched appearance at their upper ends due partly to the relatively large necrotic mass within them and partly to wasting and fibrosis of the affected bellies below

Treatment. (1) ACUTE PHASE. This must above all else be timely To relieve arterial occlusion late will do nothing to help the infarcted forearm and will imperil the patient s life by flooding his circulation with toxic products.

If changes of position (or one cautious manipulation of a fracture) do not restore the radial pulse the antecubital fossa should be explored and the cause of the brachial arterial obstruction determined. If external pressure (e.g. vessel nipped between bone fragments) is found the vessel is disengaged. If irreparable arterial damage or thrombosis are present the damaged segment should be excised. If there is only traumatic arterial spasm it is seldom justifiable to resect, though we have to remember that persistent spasm due to invisible intra arterial damage may be cured by resection. Unfortunately we have no reliable relaxant drugs for local use though Papaverine or Eupaverine may be tried A sympathetic block should be tried.

Post operatively everything is subordinated to sustaining the local circulation. Fractures simply do not matter at this stage. The limb is supported in whatever manner embarrasses the circulation least. Generally it is cooled. Pain and restlessness must be relieved. Tissue damage, ischæmic and surgical, calls for prophylactic antibiotics.

(2) PHASE OF DEVELOPING CONTRACTURE. A programme of sustained passive exer cises together with what active movement the patient can achieve is carried out to preserve joint mobility A lively splint with individual elastic traction to the digits (Seddon) is employed to oppose the steady pull of advancing fibrosis (Fig. 268)

Seddon in 1956 reported most encouraging results from excision of the infarct, on the analogy of cases of traumatic ablation of forearm muscles which do not develop any contracture. The supposition is that the infarct provokes a continuing fibrosing foreign body reaction around itself If this be so excision of the infarct should arrest the fibrosis It appears to do so The timing of the intervention is important. If it is too soon it may

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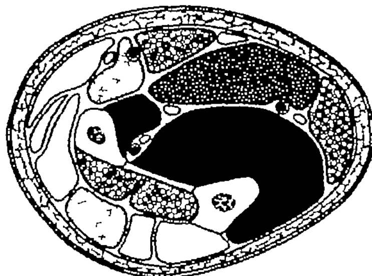


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be difficult to assess the extent of irreparable damage. If too late increasing fibrosis may trap structures that might have escaped. Seddon advises waiting three to six months.

A successful outcome of the excision halts the fibrosis and leaves the way open to the use of some of the more familiar tendon transfers employed in traumatic or paralytic loss of muscle.

(3) Phase of Fully Developed Contracture. The problem is that the surviving flexor muscles are relatively too short. Max Page devised a slide operation to shift the flexor origin distally. Often the gain is inadequate and Scaglietti has extended the principle into an heroic separation of the entire flexor mass, with its nerves and muscles, from

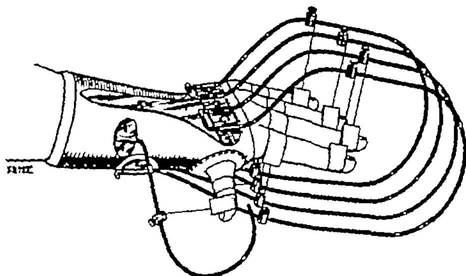


Fig. 268. Modified from Seddon. Splint designed to permit individual elastic traction on each digit through 180° of arc, from tight flexion to full extension of the interphalangeal joints.

the elbow, forearm bones, and interosseous membrane in order to shift the whole mass distally and has achieved some startling results. *Ischæmic fibrotic matting of tendons* at hand and wrist may defeat the procedure however.

Skeletal shortening (excision of proximal row of carpus or formal shortening of forearm bones) may suffice but is unselective in its effects on the variously damaged muscles. Individual tendon lengthening is selective but the risk of adherence is great.

Arthrodesis of the wrist sets free dorsiflexors for transfer to flexors but Athol Parkes points out, that, without arthrodesis, if Extensor Carpi Radialis longus *only* is transferred to the divided Profundus (after section of all the wrist and finger flexors) its inadequate range as a finger flexor can be supplemented by dorsiflexion of the wrist by the remaining wrist extensors.

The numerous variations on these basic procedures underline the inadequacies of any one of them. *The problem is always one of the greatest difficulty.*

There remains the problem of the nerve damage. If the ulnar nerve is infarcted a nerve pedicle graft (Strange) may be developed from it to replace a median gap. Otherwise a free graft must be obtained elsewhere.

De Quervain's Disease

Stenosing teno-vaginitis at the radial styloid was described by de Quervain in 1895 though the condition of "washerwoman's sprain" had been described before this. This common condition is a fibrotic thickening, of uncertain origin, of the fibrous component of the osseo-fibrous tunnel at the radial styloid, which houses the tendons of extensor pollicis brevis and abductor pollicis longus. Whereas the normal fibrous outer sheath at this point is approximately $\frac{1}{32}$ in. thick, in de Quervain's disease it may be as much as $\frac{1}{4}$ in. thick and presents a dense hard fibrous cut surface when divided. This degree of

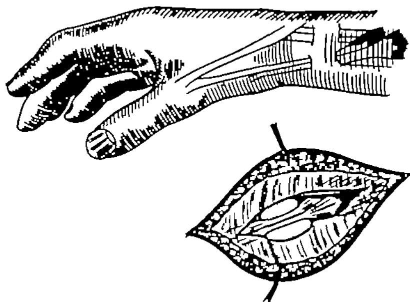


Fig. 269 The roof of the fibro-osseous tendon canal at the radial styloid laid open to show the dense localized fibrous thickening nipping the tendons of Abductor pollicis longus and Extensor pollicis brevis.

thickening encroaches on the tendon canal as well as producing a localized lump visible clinically (Fig. 269).

The tendons so pinched are subject to chronic frictional irritation. Their mucous sheath becomes thickened and it and the tendons display a pink reactionary vascularity. The smooth surfaces of tendons and sheath may be opaque, roughened and even display small fibrinous flakes, though usually the disability limits activity so that such a severe reaction cannot be provoked by use.

The disability produced is a painful inability to use the thumb, particularly in abduction or when the hand is deviated ulnarwards. There is marked tenderness of the local swelling.

Any painful lesion in the adjoining carpus may cause confusion, but the true condition is nearly always absolutely typical. If the patient's hand is grasped as for a handshake and deviated to the ulnar side it may cause very little or no pain. But if the thumb is grasped with the hand and also ulnar deviated the patient will wince with pain as the pull comes on abductor longus and extensor brevis.

come steadily if infrequently to light of chronic disability in people whose work involves rapid repetitive use of the hand and finger tendons, e.g. typists. Once established the condition always improves with rest but tends to recur immediately the repetitive activity is resumed. The only reasonable treatment is a change of job, for at least several months.

Tuberculous Tenosynovitis

This condition, a disease of adult life most often presents as a so-called *Compound Palmar ganglion* though any of the tendon sheaths of the hand can be affected individually. A compound palmar ganglion is merely a chronic tenosynovitis affecting radial or



FIG. 270 Distended flexor sheaths in Compound palmar ganglion, with well marked "waist" corresponding to the transverse carpal ligament, seen divided in the foreground.

ulnar bursæ or both, and therefore presenting swellings both in the palm and proximal to the wrist, separated by the constriction of the carpal tunnel. It is not necessarily tuberculous though the term is usually employed in this connection. Though the tuberculous condition was described as far back as the early 18th century its real nature was not fully realized until Goldman (1896) implanted some of the "melon seed" bodies, that are commonly found in the tendon sheaths, into the peritoneal cavities of guinea pigs, which then developed tuberculosis.

Clinically slight aching discomfort in the hand and fingers usually precedes any physical signs in a patient who may or may not have overt tuberculosis elsewhere. The ulnar bursa or both ulnar and radial bursæ are affected more often than the radial bursa alone. The extensor sheath on the dorsum of the wrist is involved more commonly than may be realized. The thickening of the synovial sheath naturally shows where it is least constricted by fibrous sheath, viz.—proximal to the wrist, in the palm and, in the fingers, on the palmar aspects of the inter phalangeal joints (Fig. 270). "Fluctuation" between the proximal and distal swellings of the ulnar and radial bursæ can often be elicited but it is rarely the result of actual fluid distending the sheath. The thrust is transmitted through

swollen "boggy" synovial sheaths or sometimes, when it may be accompanied by a soft "bubbling" crepitus, by the actual movement of a mass of melon seed bodies to and fro

Macroscopically the sheaths often present a normally glistening outer surface but the opaque pinkish thickening of their synovial lining obscures the tendons which normally show through the sheath When the sheath is opened the characteristic melon seed bodies escape and the parietal and visceral surfaces of the sheaths are seen to be covered with velvety tuberculous granulation tissue. This may invade the actual tendon

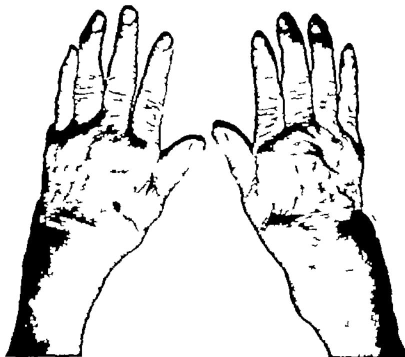


FIG 271 Distension of extensor sheaths in Rheumatoid tenosynovitis.

substance and indeed may though very rarely lead to rupture of the tendon, but often the tendons appear macroscopically normal when the synovial membrane is removed

Treatment. Even before the advent of modern anti tuberculous drugs excision of the affected sheaths had a good reputation. The disease always seemed indolent, seldom proceeded to real breakdown with caseation and the results were always recorded as encouraging. But recurrences occurred and though re-exploration and a fresh *toilet* often appeared to work well it may be surmised that the good reputation of excision rested more on the immediate, and admittedly fairly durable functional result than on any local cure. Recurrences were and are more common than the procedures reputation suggested This said it must not be denied that the restoration of function (often in any case not too severely limited) was excellent. However excision needed to be followed by immobilization, of the wrist if not of the fingers, for several months. Excision alone and immobilization alone were insufficient.

restore both mobility and stability in a flail joint, yet an arthrodesis might be preferable if it set free those same tendons for the mobilization of other joints.

We may say then, that, *other things being equal* the surgical treatment of stiff or unstable joints in the hand comprises

(1) Operations upon the motor apparatus (muscles and tendons), which are considered separately

(2) Arthroplasty

(3) Arthrodesis.

Arthroplasties in the Hand

In general an Arthroplasty means any surgical procedure, on soft tissues or bone, that restores mobility to a joint, but it is customary to separate off such soft tissue procedures as capsulectomy or excision of collateral ligaments, reserving the term arthroplasty for procedures on bone.

The prognosis with soft tissue procedures is very different from those on bone. In general it may be said that where bone ends and articular surfaces are damaged the results of arthroplasty have been disappointing. But where undamaged articular surfaces can be freed to move again by the release of scarring and contractures the outlook is immeasurably better and is none the worse for the fact that atrophic changes may have occurred in the motionless joint surfaces, which may even have adhered together Such joints can be made to move again.

Particular Arthroplasties

Despite disappointing results evidence accumulates that failures may be due to faulty technique rather than to unsound procedures.

In the metacarpo-phalangeal joints arthroplasty promises better from the start since these joints are supported by multiple tendons on all sides In the interphalangeal joints the presence of tendons only on the extensor and flexor surfaces gives an arthroplasty an inherent lack of stability in extension. This may be tiresome but of secondary importance, as the restoration of flexion, and thereby grip is usually the main objective and when gripping the unstable finger receives support from its neighbours. We must remember too that a finger stiff in all or any of its joints means some restriction of movement in the muscles of adjacent fingers, so that improvement in grip after an arthroplasty is unlikely to be confined to the finger in question. (By the same token an arthrodesis may stiffen more than we bargain for)

At the same time stability in a position of function is an asset not to be tampered with lightly and it could be folly to mobilise a proximal interphalangeal joint stiff in a useful position of flexion—at least till we are surer of our methods of arthroplasty Selection of cases must be realistic and the procedure reserved for gross and hampering stiffness in extension especially when lateral angulation or rotation are present. Moreover the deformity must not have been present too long and one relies on considerable co-operation from the patient.

Elaborate refashionings with the interposition of fascia lata steel caps, plastic prostheses etc., between the bone ends have been disappointing. The reason is not far to seek and it seems clear that the wide exposure and disturbance to gliding surfaces, is sufficient explanation On the other hand the simplest arthroplasty by excision of a bone end

(usually the head of the proximal bone), is proving much more encouraging. But, as in the Keller's operation on the Hallux, the essential is to remove enough bone and *to maintain length* by traction for sufficiently long. It is imperfectly appreciated that in such arthroplasties by excision the aim is the creation of a flexible block of fibrous tissue between the bone ends. Only if such a block is long enough can it provide a useful range of flexion by bending, whether or not it develops a new joint cavity within itself So it is not surprising to see traction recommended for *six weeks* after operation by Carroll and Taber whose results are impressive enough to compel reappraisal of the whole question

In the proximal interphalangeal joint a simple mid-lateral approach is used and with minimal disturbance of soft tissues, one third *or more* of the distal part of the proximal phalanx is removed, great care being taken to get the line of section at right angles to the shaft.

In the metacarpo-phalangeal joint the approach may be either mid-dorsal, splitting the extensor tendon longitudinally or dorso-lateral, when the bone is approached between the lateral border of the extensor tendon and the posterior border of the dorsal interosseus.

In after treatment the importance of long continued traction has been mentioned During the subsequent active remobilization strapping the affected finger to its neighbour helps prevent movement other than in the plane of normal flexion and extension

One particular arthroplasty deserving separate mention is excision of the trapezium—usually for degenerative arthritis of the carpo-metacarpal joint of the thumb which is quite common and disabling and appears to affect women more than men. Subluxation proximally and radially of the base of the thumb metacarpal commonly occurs, and the thumb is often fixed in adduction so that there is no proper pinch between thumb and index. In addition the condition is painful. Excision of the trapezium followed by immobilization of the thumb in the position of normal pinch, for several weeks before remobilization, is well worth while. In fairness it must be said that arthrodesis in the same position is equally effective, as in the case of a middle aged ambidexterous boot repairer who has been restored to normal activity by an arthrodesis on one side and an arthroplasty on the other and is unable to say which hand is the better

Capsulectomy Similar approaches—mid lateral for the proximal interphalangeal joint, dorsal tendon-splitting for the metacarpo-phalangeal joint—give access to the collateral ligaments. Simple division of these ligaments usually results in rapid healing in the position of contracture. Actual excision of the major part of the ligament is necessary To reach it, it is necessary to traverse the fascial sheet extending from the extensor mechanism on the dorsum to the flexor tendon sheath If this is preserved and repaired it compensates for the loss of lateral stability until healing and reconstitution of the ligaments have occurred. Through the same approach it is possible to divide the volar plate of the capsule if it is scarred and contracted or to tackle adherence of capsule to underlying bone.

Other Soft Tissue Procedures. Restriction of joint range may be due to factors remote from the joint, such as fascial contractures (e g. Dupuytren), shortening or adherence of intrinsic muscles, extensors or flexors. Capsulectomy may be insufficient or even unnecessary and such procedures as tenolysis of the extensors, a release of short intrinsics or even replacement of flexors by a free graft may be necessary (see section on tendons and Volkmann's contracture).

Arthrodesis in the Hand

As elsewhere arthrodeses are carried out for two main reasons, the relief of pain in damaged joints and the restoration of stability In paralysis an additional objective may be the setting free of tendons which may operate other joints after suitable transfers.

Arthrodesis of the terminal interphalangeal joint of a digit in moderate flexion is a simple and useful procedure. After repair of a flexor profundus tendon by a free graft we commonly achieve good flexion at the proximal interphalangeal joint but restricted flexion at the terminal joint. So after flexor tendon damage if the sublimis is working well arthrodesis of the terminal joint in flexion is a simple solution with less exacting after-treatment than tendon replacement.

Paralysis of a flexor destroys stability and the case of a farmer recovered from a polyneuritis, whose sole real persisting disability was paralysis of the right flexor pollicis longus provides a vivid illustration. Not only could he not pick up a pin or a sixpence but also as a champion clay pigeon shot, he was gravely frustrated by poking the extended right thumb in his eye every time he brought his gun to the shoulder A simple arthrodesis of the interphalangeal joint in flexion rapidly restored his equanimity

Arthrodesis of a proximal interphalangeal joint is harder to decide about. A digit fixed in flexion at this joint prevents putting the flat hand into any narrow space and may be quite unsuitable for a man working with machines yet perfect for a gardener

Arthrodeses of the metacarpo-phalangeal joints are apt to provide surprises, fusion of one sometimes producing quite unacceptable restriction of movement in its neighbours

In the thumb however the contra-indications are less. Its prime function is opposition to the index and middle fingers Provided the arthrodesis permits this a thumb with very little movement at all carries very little disability Powerful gripping is a function primarily of the fingers with the thumb acting as an almost fixed pillar

In all these joints the simplest technique is simple erasion of the articular surfaces and fixing the bone ends with crossed transfixion pins cut off short beneath the skin for removal later Elaborate graft-carpentry is unnecessary and the exposure necessary for it imperils free tendon movement.

Gross arthritic disorganization of the radio-carpal joint, with pain brooks little argument and a solid fusion is essential the only reasonable alternative being protection from painful strains by external splinting.

Paralytic instability is another matter and calls for careful thought. It is tempting to grab the opportunity of acquiring two wrist flexors and three extensors for transfer to other uses. But, for example, the preservation of automatic opening of the hand by gravity acting through a tenodesis of the common extensors in the presence of a mobile wrist may outweigh all other considerations It is not possible to consider all the pros and cons here but it is worth remarking that as we go proximally up the arm the indications for fusion, of wrist, elbow or shoulder become progressively more debatable

The decision taken, the technique is not usually troublesome Generally a dorsal approach is satisfactory since the extensor tendons tolerate the necessary interference well. A curved flap of skin with its base to the radial side keeps the suture line off the bone graft and disturbed extensor tendons. Moreover it preserves the cutaneous nerve supply of the dorsum of the hand coming from the radial side better than most incisions. Such

a flap can embrace the lower end of the ulna which is often removed for the restoration of pronation and supination

It is doubtful if it is ever worth inflicting on a patient the inability to walk normally for many weeks that is the price he pays for a cortical graft taken from a tibia. A cancellous block from the ilium slotted into the dorsal surface of the radius and carpus after excision of the radio-carpal joint is entirely adequate if subsequent plaster immobilization is sufficiently firm and prolonged. A refinement is to slot the proximal end of the graft into the distal face of the radius thereby preserving intact the dorsal tendon grooves.

Erasion of carpal joint surfaces preparatory to reception of the graft deserves special mention. A clean erasion with the osteotome of the radio-carpal articular surfaces is desirable. But the detailed erasion one by one of the intercarpal surfaces, as sometimes recommended, is apt to leave a number of sadly diminished avascular "kernels" of the carpal bones, the revascularization of which has to precede, and therefore delays, the incorporation of the graft.

By whatever method the final position is important and rather than express it as so many degrees of dorsiflexion, or "the position of function"—standards which will be variously interpreted—it may be said that we will not be far wrong if the wrist ends up in the position it assumes when the loosely clasped fist and forearm lie pronated in front of one on a table.

A word on the special problem of the Rheumatoid wrist is needed. Commonly these disorganized wrists present a forward and proximal dislocation of the carpus on the radius. When exposed the whole field is apt to present a daunting spectacle of grey unhealthy granulations, ruptured extensor tendons, and the worst sort of friable bone, full of cavities. Under these conditions precise graft carpentry is not only unnecessary it is impossible. Rheumatoid joints exhibit a readiness to fuse and if only a rough and ready pair of raw bone surfaces can be fashioned and apposed they will almost certainly unite if effectively immobilized by transfixion pins and a plaster In such wrists the lower end of the ulna is usually dislocated and its removal is therefore necessary Disability due to undue mobility of the remaining lower end of the ulna after this procedure is rare and should be treated if it arises by an *ad hoc* sling procedure.

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CONGENITAL DEFORMITIES OF THE HAND

The number of developmental aberrations that are possible in the hand is of course astronomical They have been the subject of earnest classification by ardent systematists but while some such tidying of an untidy group of conditions is essential the complicated nomenclature that has resulted is possibly less desirable. Here it is possible to consider only a few of the commoner forms and perhaps to whet the reader s appetite for more complicated studies

All congenital abnormalities fall into two categories—too much (or too many) and too little (or too few). The causes are not fully understood. Whereas on the one hand many are obviously hereditarily transmitted, on the other each hereditary chain of transmission has to have a beginning. We know that, experimentally carefully timed "insults" to developing chick embryos, by injecting insulin into the incubating eggs, not only produce congenital deformities but can be made, by suitable timing, to produce particular congenital deformities say a club foot, at will (Duraiswami) This fits together with the clinical observation that maternal illness in early pregnancy notably rubella, is very apt to be followed by the birth of a congenitally deformed infant. The subject is fascinating but more detailed consideration is beyond the scope of this contribution.

From a practical view point most of the treatment of these conditions is surgical, either ablation of supernumerary portions or reconstruction of deficient ones. The indications and contra-indications are, then, important.

The hand must not only work but must be able to be put to work Deformity joint stiffness, or paralysis proximally in the arm may be of sufficient degree to spoil all

reconstructive surgery in the hand. The arm must work normally if the hand is to be put where the patient wants it, or else reasonable preliminary reconstruction of the arm must be possible. Not only this, but also the patient must be capable of controlling and using the hand so that reconstruction may be quite out of place in the presence of mental defects. Cosmetic indications are generally subsidiary though far from unimportant, but may be the only ones in grotesque malformations.

In general, surgical correction should be undertaken as early as possible—even in the first year Cerebral patterns of use of the deformed hand do not then have to be un learned, the infant laying them down from its efforts to use the reconstructed hand. Older than this, though still in quite tiny children, there develops a striking ability simply to leave a digit out of the normal activity of the hand, and to do this becomes the fixed pattern of use in that particular hand. It may then be better to delay reconstruction till some real co-operation in after treatment can be counted on.

Such early reconstruction however carries the obvious risk of interfering with growth either through epiphyseal damage or the tethering effects of scars, so that procedures must be chosen critically Moreover tiny children are of course inveterate wrigglers and rival Houdini himself in their ability to escape from restraining apparatus of all kinds Nevertheless if they can be mastered in this respect they tolerate well the awkward cramped positions that skin plastic procedures may demand. In children of school age loss of school time is an important factor Moreover children are cruel critics and it is as well for the best possible cosmetic result to have been achieved before a child meets ridicule at school.

PRINCIPLES OF RECONSTRUCTION

(1) Supernumerary Digits (Polydactyly)

The treatment here is amputation and it seldom poses any great problems. Some times it is difficult to be sure which digit will develop if left, and it may be necessary to wait till epiphyses are visible in the radiograph (Fig. 272)

(2) Too Few Fingers, and Too Little (Oligodactyly Ectrodactyly)

If the fingers present are well developed there may be no problem. If the missing digit is the thumb the hand is devoid of pinch. This may be remedied by a pollicization of another digit. This poses more troublesome skin plastic problems than in the case of partial loss of the thumb through injury A wide cleft between two digits has to be made and lined with skin, usually by means of pedicled grafts, before a rotatory osteotomy can turn one to face the other like a thumb

There may be no suitable digit to pollicize and the problem may be one of constructing a thenar stump to which rough opposition of a digit may be possible. Such a stump must have sensitive skin on its working surface If not the patient will be unlikely to use it at all.

Again the digit may be so rudimentary (Fig. 273 (*a* and *b*)) that all one can do is to make a cleft in the metacarpus so that one or more metacarpals on either side of the cleft may develop some adduction range and so provide a side to side pinch.

One may indeed be faced by a congenital cleft hand. Sometimes a complete ray (phalanges, metacarpal and part of the carpus) may be missing from an otherwise normal

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PRINCIPLES OF RECONSTRUCTION

(1) Supernumerary Digits (Polydactyly)

The treatment here is amputation and it seldom poses any great problems. Sometimes it is difficult to be sure which digit will develop if left, and it may be necessary to wait till epiphyses are visible in the radiograph (Fig. 272)

(2) Too Few Fingers, and Too Little (Oligodactyly Ectrodactyly)

If the fingers present are well developed there may be no problem. If the missing digit is the thumb the hand is devoid of pinch. This may be remedied by a pollicization of another digit. This poses more troublesome skin plastic problems than in the case of partial loss of the thumb through injury A wide cleft between two digits has to be made and lined with skin, usually by means of pedicled grafts, before a rotatory osteotomy can turn one to face the other like a thumb

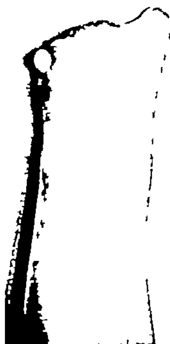
There may be no suitable digit to pollicize and the problem may be one of constructing a thenar stump to which rough opposition of a digit may be possible. Such a stump must have sensitive skin on its working surface If not the patient will be unlikely to use it at all.

Again the digit may be so rudimentary (Fig. 273 (*a* and *b*)) that all one can do is to make a cleft in the metacarpus so that one or more metacarpals on either side of the cleft may develop some adduction range and so provide a side to side pinch.

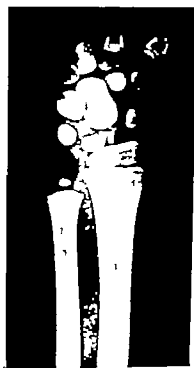
One may indeed be faced by a congenital cleft hand Sometimes a complete ray (phalanges, metacarpal and part of the carpus) may be missing from an otherwise normal



FIG. 272. Polydactyly Hand with supernumerary thumb and little finger



(a)



(b)

FIG. 273 (a and b). Rudimentary digits. Ectrodactyly

hand Deepening of the cleft and removal of any obstructing fragments of the missing ray permits a fairly simple side to side closure of the cleft without difficult skin plastic procedures. Sometimes the cleft will separate two mirror-image halves comprising two ring and two little fingers—the rays springing from two ulnæ In addition to closing such a cleft the problem of pollicizing the little finger on the "radial" side of the hand will arise

(3) Webbed and Confluent Fingers (Syndactyly)

This is the commonest deformity of the hand The condition may vary from mere webbing together by skin of two otherwise normal digits to a fusion of all the fingers (rarely including the thumb) with partial or complete bony fusion of adjacent rays,

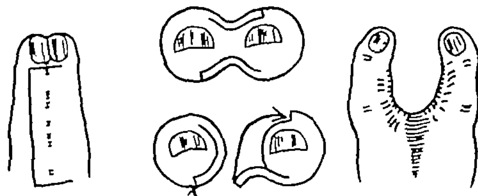


Fig. 274 The unsatisfactory contracture of the web with curvature of the digits likely to follow use of the method of separation shown.

together with elimination of the muscles and neuro-vascular bundles which ought to have developed on the facing surfaces of the bony rays, had the latter developed separately Two fused digits may share a single tendon. If separated, their joints may have no capsule on the separated aspects.

It follows from these considerations that unless the confluent fingers are individually fairly well developed it may be impossible to separate them satisfactorily In a complete syndactyly to fashion a cleft between the middle and ring rays may produce better function than separating four digits at all costs.

Assuming that the bone and joint development of the fused digits seems promisingly adequate their separation is a matter of skin plastic procedures. The old fashioned dorsal and volar flaps were not successful for three reasons. They rarely produced sufficient skin and sloughing of their margins with increased scarring was common. Their use led to a scar running down the side of one finger across the web and up the side of the other finger Contracture, especially of the web portion of the scar turned a long V into a short U the web being drawn distally to reproduce a partial syndactyly (Fig. 274). Moreover with growth of the digits the longitudinal scars did not keep pace and the terminal phalanges of the adjacent digits were pulled out of line, inwards towards each other

To get a satisfactory separation it is essential to fashion dorsal and palmar flaps to fold in over the bare area left by the excised web In the length of the finger the line of

excision should be wavy or zig-zag so that no longitudinally pulling scar can deform the digits. The bare areas on the facing surfaces of the digits are covered with rather thick split skin grafts (Fig. 275)

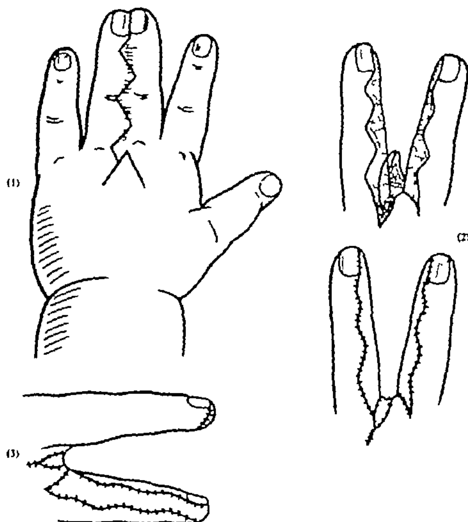


Fig 275 Satisfactory separation requires

(1) Wavy or zig-zag skin incisions

(2) Cross over flaps fashioned to cover the web.

(3) Covering the bare areas on the separated faces of the digits with free grafts.

(4) Club-hand Congenital Absence of the Radius

When the radius is absent completely or in part, the radial half of the carpus, and the *thumb and index are also apt to be deficient in greater or lesser degree.* The muscles of the radial side of the forearm and hand may also be abnormal. Correction of the extreme radial deviation of the hand which is associated with absence of the radius needs to be planned with these factors in mind. To get the hand in line with the forearm is a basic

sential since only in such alignment can the forearm muscles work the digits with any rength. To do so one may follow the same line that is used in the foot—first manipula on and stretching, followed by corrective splinting. Even skeletal traction by wires

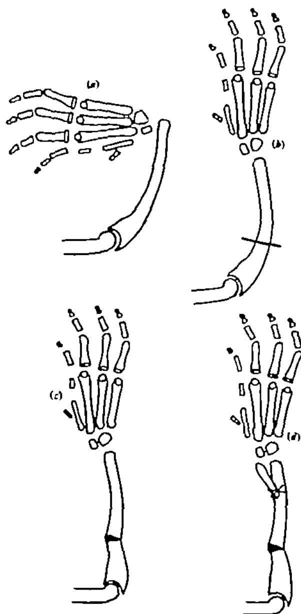


FIG. 276. Scheme of correction of Club hand.

(a) The essential deformity—skeletal (and associated soft tissue) deficiencies on radial side of fore arm and hand.

(b) Correction of radial deviation of hand and placement of carpus squarely over the distal end of the ulna.

(c) Osteotomy of curved ulna.

(d) Insertion of fibular graft to prevent recurrence of radial deviation.

through the metacarpals has been used The younger the patient the more will these methods achieve, but by themselves they are not enough. It is necessary to get the carpus fully released, and placed beyond the distal end of the ulna and only open division of soft tissues on both radial and ulnar aspects of the wrist will permit the necessary displacement ulnarwards (Fig. 276 (*a* and *b*)) It needs to be remembered that the median

nerve is a superficial structure on the concave side of the wrist in these cases. Even after corrective splinting the skin may be tight after reposition of the hand but seldom so much so that flexion of the elbow will not relax it.

Subsequently the provision of a bony prop for the carpus on the radial side is necessary if the hand is not to pull slowly back into the deformed position. The upper end of the fibula has been successfully used It is removed with its epiphysis, this end of the bone being placed under the carpus, the divided end of the shaft being slotted into the ulna so that a Y shaped bifurcated forearm bone results when union is complete (Fig. 276 (*d*)). The epiphysis will ossify but does not contribute any growth in length. In addition an osteotomy—sometimes to be repeated after a year or two—is often necessary to correct the usual pronounced curve in the shaft of the ulna (Fig. 276 (*c*))

The above method if successful can result in a wrist as satisfactory for its mobility as its alignment. Another approach is to concentrate more on finger function than a mobile wrist and to correct the angular deformity by repeated osteotomies of the ulna, ending up with a carpo-ulnar fusion in the best position attainable It has the merit of employing simple procedures even if they are multiple.

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TUMOURS OF THE HAND

The hand is clearly capable of producing any tumour of ectodermal or mesodermal origin but while some are of great rarity a few are common. It is not proposed to treat the subject exhaustively but to deal in detail only with the commoner varieties, from a clinical viewpoint. For detailed pathological features the reader must consult more specialized treatises.

BONE TUMOURS IN THE HAND

(1) Tumours of Cartilage or Cartilage Precursors

(*a*) Multiple Ecchondromata. While the condition is common affecting the long bones ecchondromata in the hand are unusual. "Tumours" *clinically* they are, *single* or multiple, to be regarded as a systematised anomaly of skeletal development and only enter the class of new growths proper if they proceed to malignant change. Any spurt of growth should be regarded as indicating this change and the ecchondroma should be removed. Its periosteal covering should be removed with it.

When there is no actual spurt of growth the swelling may call for removal on account of its size or situation *interfering with function. Fig. 277 (a and b), illustrates an ecchondroma* of the proximal phalanx of the little finger

(*b*) Juxta Cortical Chondroma (syn. periosteal chondroma) A rare, usually small hondroma, affecting short or long tubular bones characterized in the X-ray by a soft issue shadow with a corresponding cortical indentation. It is often sited at a ligamentous ttachment. These tumours are benign and do not recur after local removal

(*c*) Enchondromata These are common in the hand especially in the phalanges. They may be solitary or multiple. The solitary variety are comparatively rarely discovered efore the age of 10 They are insidious in appearing and often are discovered only

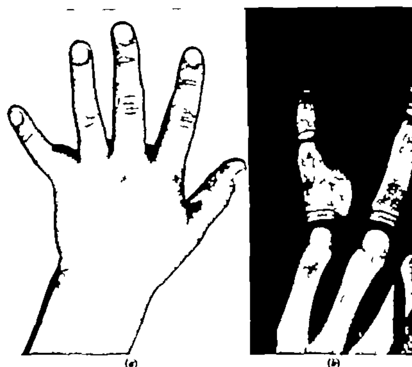


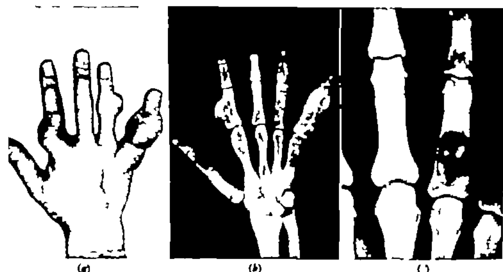
Fig. 277 (*a* and *b*). Ossifying ecchondroma of proximal phalanx of little finger

because of some trauma. If discovered because of spontaneous pain or the rapid appearance of a swelling they should be viewed with suspicion. With or without any clinical swelling the X ray picture is usually typical—a discrete circumscribed area of loss of bone pattern, often eccentrically placed and rarely if ever involving an epiphysis, usually faintly trabeculated, and showing spotty calcification. Even without the latter two features cystic appearing lesions in the phalanges and metacarpals are very probably enchondromata (Fig. 278 (*c*))

Treatment by curettage and packing the cavity with cancellous chips gives uniformly good results and recurrences are rare.

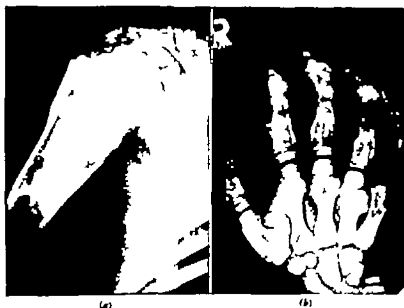
Skeletal Enchondromatosis The multiple varieties are of considerable interest.

Multiple enchondromata (Fig. 278 (*a* and *b*)) may be seen in the hand and feet alone but much more commonly other parts of the skeleton are involved Here especially though sometimes also in the hands a semblance of order in the cartilaginous disorder is apparent. The parallel if irregular columns of cartilage extending longitudinally from the



(a) (b) (c)

FIG 278 (a and b). Multiple Enchondromata of bones of hand.
(c) Solitary Enchondroma of Phalanx.

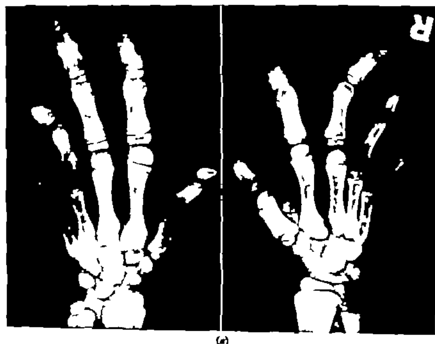


(a) (b)

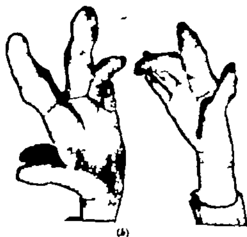
FIG 279 Ollier disease
(a) Humerus (b) The hand

epiphysis into the metaphyses of long bones underline the fact that this is a systematized anomaly of endochondral ossification. In Ollier's disease (Fig. 279 (*a* and *b*)) also the affection has a pronounced tendency to affect the limbs unilaterally or predominantly so. *In the hands the classic columnar arrangement of the cartilage in the metaphysis* may be obscured by the smallness of the bones affected.

In Mafucci's disease the enchondromatosis is associated with *multiple hæmangiomata* of the skin, often with phleboliths: grotesque distortions and localized gigantisms result (Fig. 280 (*a* and *b*)). The exuberant appearance of the clinical deformities is related



(*a*)



(*b*)

Fig. 280 (*a* and *b*) Mafucci's Disease. Hand showing grotesque local gigantism.

to a greater cellular activity and growth potential, and malignant metaplasia is correspondingly commoner and occurs at times in multiple foci simultaneously

The treatment, surgically speaking, is a matter of *ad hoc* ablation or extirpation dictated by constant watchfulness and the mechanical needs of the hand Success here, as in statesmanship, depends on a realistic appraisal of the possible

(*d*) BENIGN CHONDRO-BLASTOMA.* A tumour of long bones of exceeding rarity in the hand, though described.

(*e*) CHONDROMYXOID FIBROMA * A benign tumour only classified of recent years, affecting the lower limb preponderantly but its affecting the small bones of the foot suggests that it will turn up in the hand if it is looked for

(2) Tumours of Osteoblastic Origin

(*a*) OSTEOID-OSTEOMA. This tumour is fairly common in the hand, in the bones of the carpus, and perhaps especially in the scaphoid (Fig. 281).

Clinically it is characterized by pain of a persistent and boring character occurring independently of injury strain, or hard use of the hand, rather characteristically nocturnal and said, though this may be accepted with caution, to be so constantly as to be almost specifically relieved by aspirin. Despite the almost universal recognition among orthopædic surgeons of this comparatively recently classified tumour (1935 Jaffe), too many patients, beset by pain, are still permitted to complain their way into the consulting rooms of psychiatrists. The pain, occasionally remote from the tumour is usually an accurate pointer to its situation. As this tumour is always small and buried in the bone local physical signs, apart perhaps from tenderness, are non existent.

Radiologically a film not of the highest quality may show only a dense area of sclerosis suggesting chronic inflammation. Better films will show a small usually quite clear cut, round translucent area in the centre of the sclerosis, often containing in its turn a small central dense portion suggestive of a sequestrum.

The treatment is removal The tumour is a minute "raspberry" of vascular cancellous bone that shells cleanly out of its sclerotic bed leaving a perfectly smooth rounded cup behind it. On section it shows the usual pattern of finely trabeculated atypical bone richly covered with osteoid tissue, against a background of osteoblastic vascular connective tissue.

Removal gives instant and lasting relief and no recurrence after removal has been reported.

(*b*) OSTEOGENIC FIBROMA. Though these tumours have a predilection for the vertebræ they have been described in the hand and foot In the hand though they may expand a bone they rarely break through the cortex The X ray appearance is of a cystic lesion, somewhat trabeculated and both from this point of view and on section the tumour is fairly easily confused with giant cell tumours.

The diagnosis is unlikely to be made unless by biopsy The indication for removal is interference with function through size or situation and the results are excellent.

(*c*) OTHER OSTEOID FORMING TUMOURS. Rare but showing a predilection for the bones of the hands and feet, is a group of localized expanding tumours of some size, tending to exuberant growth short of malignancy and characterized by abundant osteoid formation. They seem to occur in young people and are amenable to local resection.

* The reader is referred to the works of Jaffe and Lichtenstein for further details of these two tumours.



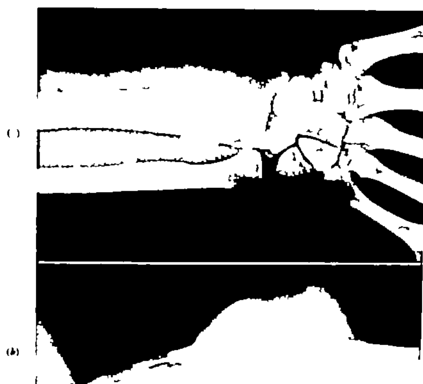
Fig. 281 Osteoid osteoma of the proximal pole of the Carpal Scaphoid.

(3) Tumours of Non-osteoblastic Connective Tissue Origin

(*a*) Non-osteogenic Fibroma. Not yet described in the hand.

(*b*) Giant Celled Tumours of Bone. Many of the so-called "variants" of the tumour are nowadays tending to be grouped under other headings—"non-osteogenic fibroma," "chondromyxoid fibroma" etc. Giant celled tumours occurring in the hand other than in the lower end of the radius are probably not true examples. In the lower end of the radius they are relatively common. As elsewhere the tumour is often advanced before it is discovered because of pain or swelling, or a local infraction. There is no typical radiographic appearance, the so called typical soap bubble appearance generally belonging to one of the "variants." Any area of irregular rarefaction with expansion and thinning of the cortex is suspect. Treatment should not be embarked upon without a biopsy. True giant celled tumours are excessively rare under the age of 20.

The tumours are mostly only locally invasive and probably some 50 per cent are safely amenable to removal by resection or curettage. The remainder are either more aggressive, recurring after local removal or frankly malignant.


(a)
(b)

While it is true that the less aggressive tumours are amenable to Deep X ray Therapy probably only 50 per cent are really safely so Recurrence after irradiation or curettage presents a state of affairs calling for very difficult decisions. Unquestionably a block extirpation at the outset is the ideal but it is rarely possible except at great functional cost owing to the typical situation of the tumour

In the particular situation at the wrist, radical extirpation followed by bone grafting reconstruction is not commonly practised. Consideration of Fig. 282 (*a*, *b* and *c*) suggests that perhaps it might properly be undertaken more often if the odds against aggressiveness in these tumours are no better than roughly evens.

(4) Tumours of Vascular Origin

(*a*) HÆMANGIOMATA arising in the bones of the hand are exceedingly rare. Involvement of these bones in widespread hæmangiomatous development in the limb is commoner

(*b*) HÆMANGIO-ENDOTHELIOMATA are rare tumours anyway and involvement of the bones of the hand is likely to be by virtue of metastasis only and therefore unlikely to present any special surgical problem.

(*c*) GLOMUS TUMOURS—(HÆMANGIO-PERICYTOMATA) Two cases of these tumours arising in the phalanges have been reported. These were successfully dealt with by curettage. More commonly of course the tumours arise in the soft tissues of the finger tips, though they may occur anywhere in the body

The tumour represents an hypertrophy of the normal neuro-myo-arterial glomus—a shunt mechanism between terminal arteries and veins. It is often sub-ungual in situation and is characteristically bluish with the nail a little elevated over it. Usually it is exceedingly painful. It may produce an indentation in the underlying phalanx.

The treatment is surgical removal and recurrence is virtually unknown.

BONE CYSTS

These occur mostly in the phalanges. The simple solitary cyst is generally due to a localized osteitis fibrosa cystica. Chondromatous "cysts" belong with the enchondromata.

Young people (under 25) are affected most and the diagnosis is usually made after injury either because of a fracture into the cyst or else the cyst is found accidentally in the radiograph.

Treatment is by curettage and filling the cavity with bone chips if it is large enough. The prognosis is good.

Xanthomata, are seen occasionally in the metacarpals beginning in the epiphyses but eventually involving the whole bone. Curettage and replacement by bone chips carries a good prognosis.

Malignant Bone Tumours of the Hand

(1) OSTEOGENIC SARCOMA is rare and presents no special features in the hand. However the prognosis after *radical* local excision is fair It is usually possible to preserve some hand function.

(2) CHONDRO SARCOMA is also rare. The treatment is amputation at a level depending on the rated malignancy of the tumour

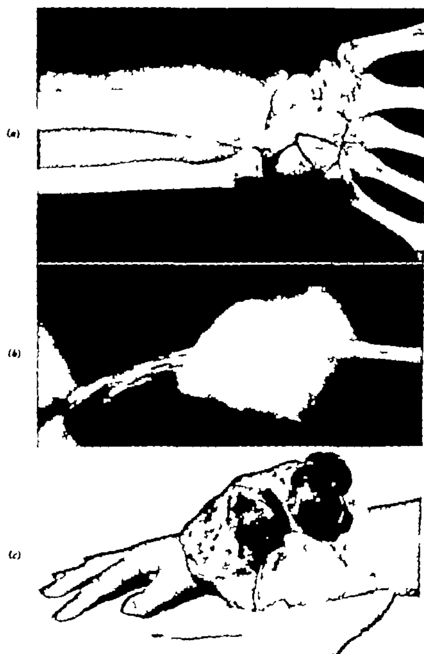


FIG. 282 Malignant osteoclastoma of lower end of Radius.
(a) Early (b) and (c) Later stages

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(2) CHONDRO SARCOMA is also rare. The treatment is amputation at a level depending on the rated malignancy of the tumour

(3) EWING'S TUMOUR is also rare The treatment is amputation. The prognosis is poor

(4) METASTATIC TUMOURS are uncommon but bronchogenic carcinoma has a peculiar affinity for the bones of the thumb

Other Tumours of Mesodermal Origin

Hæmangiomata are quite common, occurring in any structure most are plexiform proliferations of vessels True proliferation of endothelium to form cell masses (a true angioma) is rare

The tumours are usually painless, are compressible, and the radiographs may show shadows due to phleboliths.

Treatment is by excision which as elsewhere, may be tedious owing to the infiltration of the tumour between and around many important structures in a small compass in the hand

Peripheral Nerve Tumours

Nerve Sheath Tumours. Well differentiated encapsulated benign *neurilemmomata* have a tendency to occur on the flexor surface of the upper limb in relation to peripheral nerve branches. They rarely become malignant and are amenable to surgical removal.

Less well differentiated *Neuro-fibromata* are not encapsulated They occur both along the main nerve trunks and in the subepidermis. They are generally multiple and may be part of a frank Neuro-fibromatosis of Von Recklinghausen. They are apt to recur after excision and to become malignant.

Tendon Sheath Tumours

Synoviomata. The pluripotency of the synovial cell is underlined by the Protean nature of these tumours which may be predominantly fibrous, fatty cartilaginous, or Xanthomatous with foam cells and giant cells Nevertheless spaces lined with synovial cells are always to be found The benign variety is slow growing, giving rise to symptoms through its size or situation. Local excision suffices. The malignant variety rarely projects into a joint or tendon sheath but invades outwards into the surrounding tissues. It recurs locally and metastasizes readily and the prognosis is correspondingly poor The treatment is amputation.

Xanthomata. The ætiology of these swellings is not certain True neoplasia, trauma, and a defect of lipoid metabolism are all blamed.

The "tumour" is yellowish or yellowish-brown, encapsulated and benign. The microscopic picture with lipoid-containing foam cells, giant cells, and a particular fibrous and cellular stroma, is characteristic.

The swellings are usually subcutaneous, often multiple, and occur more on the right hand than the left, perhaps because of greater trauma They often occur on the dorsum of the hand where, if multiple they are referred to as Xanthoma Tuberosum (Fig. 283).

Diagnosis is not as a rule difficult and the prognosis after local excision is generally good.

FIBROMATA AND LIPOMATA are not particularly common in the hand and present no special features.

Muscle Tumours. Tumours of striated muscle appear to be unknown in the hand.

Leio-myomata however are described though rare They arise possibly from the erector pili muscles and correspondingly have only been described on the dorsum of the hand. They are well encapsulated and amenable to local excision



FIG. 283 Xanthoma Tuberosum.

TUMOURS OF THE SKIN

Cysts of the Hand

Sebaceous Cysts are unusual and are of course limited to the dorsum.

Mucous Cysts. These are thought to be due to mucoid degeneration in the cutis or subcutis. Most occur in women, and they are commonest over the terminal phalanges where they present as small bleb-like swellings (Fig. 284) Treatment, when necessary is by excision.

Epidermal Cysts. So called "implantation dermoids" are common in the hand but the term is a bad one as the cysts do not contain skin papillæ nor do they produce skin appendages (hair teeth) They are lined by squamous epidermal cells and contain a white crystalline looking substance with a high cholesterol content. The strong association of these cysts with occupational trauma and their site, commonly on the palmar surface leave little doubt that they are due to implantations by injury of small epidermal fragments. Treatment is by excision.

Malignant Skin Tumours

Melanotic Carcinoma (Sub-ungual Melanoma). This tumour was first described by Jonathan Hutchinson in 1886. It resembles a whitlow even before infection of an ulcerated surface occurs but there is usually a narrow black border to the swelling to

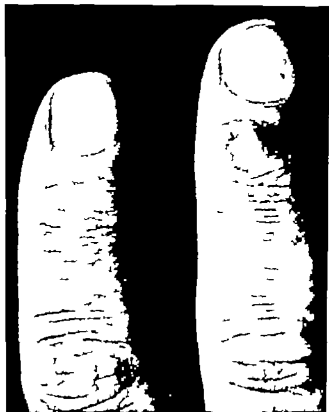


FIG. 284 Mucous cyst of terminal phalanx.

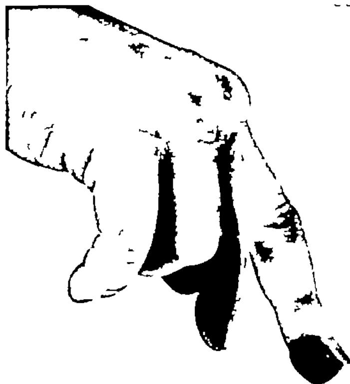


FIG. 285 Subungual Melanoma

make the diagnosis clear The mass itself may be relatively unpigmented It bursts through the nail and then fungates, or does so after a surgical decompression of the nail (Fig. 285) The tumour is not as a rule painful.

It occurs in the later years of life (av age 58 years) and nearly always occurs in the thumb

There is still no agreement as to its exact pathology Cells suggestive of a sarcoma as well as of a carcinoma are found but the tumour spreads via the lymphatic vessels. Some believe it arises from nerve tissue in the tactile end organs of the nail bed.

It is highly malignant like most melanomata, and although its situation leads to early diagnosis and early surgical ablation (together with removal of the regional glands) the prognosis is not good, less than 20 per cent surviving five years.

It must be differentiated from *Carcinoma of the Nail* which presents usually as a warty growth of the nail sulcus, commonly painful, never pigmented and tending to erode the underlying phalanx. It is a squamous celled epithelioma. The prognosis after removal of the primary and of the regional lymphs nodes is good.

Carcinoma of the Skin of the Hand

Carcinoma of the skin of the hand practically always occurs on the dorsum and very commonly develops secondarily to a pre-existing lesion, to particular trauma, or to



FIG. 286. Squamous Celled Carcinoma of Dorsum of Hand.

particular irritation Examples are chronic infections (sinuses, Chronic paronychia) burn or irradiation scars, or irritation from chemicals such as tar pitch oils or acids. Arsenical hyperkeratoses notoriously tend to develop malignant change. A precancerous dermatosis is a recognized entity

Both squamous and basal celled growths occur and because of their situation are usually recognized early enough for surgical ablation, including the lymphatic drainage, to give a good prognosis. The quite pronounced tendency to malignant changes in thermal or radiation scars is a factor justifying their replacement by skin grafts when, otherwise, the indications might not seem very pressing (Fig. 286)

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CHAPTER XV

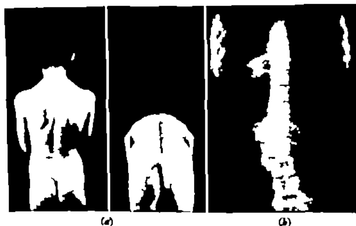
SCOLIOSIS

J I P JAMES

LATERAL deformity of the vertebral column is termed scoliosis. If correctible and without rotation it is a *postural curvature, if associated* with fixed vertebral rotation, and therefore not voluntarily correctible it is a structural deformity A third variety compensatory scoliosis arises secondarily to a short leg.

Postural Scoliosis

Postural lateral curvature is common in children. There is a single curve, more often to the left, extending over a long segment of the vertebral column, voluntarily correctible



(*a*) (*b*)

FIG. 287 (*a* and *b*). Postural scoliosis. A single left curve without vertebral rotation on forward flexion.

and disappearing on suspension or traction. Forward flexion causes the deformity to disappear and demonstrates the absence of any fixed rotation, thus excluding the presence of a structural scoliosis. Radiologically there is a single curve without rotation or structural change in the vertebræ (Fig. 287)

For many years it was believed that such postural curves were the precursors of the structural deformities of adolescence Therefore such postural habits as leaning over a school desk, carrying a satchel on one shoulder etc. were thought to be the primary cause of serious deformity It is now known that postural curves do not become structural but disappear with or without treatment.

Sciatic scoliosis is the position of greatest ease adopted to relieve tension in a nerve root lying over a prolapsed disc. It may be regarded as a transient postural scoliosis

Hysterical scoliosis is a rare phenomenon, more gross than a postural deformity but also without fixed rotation.

Compensatory Scoliosis

Scoliosis occurs secondary to a short leg or a hip deformity with apparent shortening or lengthening. It was long considered axiomatic that a short leg predisposed to structural scoliosis but a study of many hundreds of children has failed to show any correlation between the side of shortening and the convexity of the curve. A compensatory scoliosis

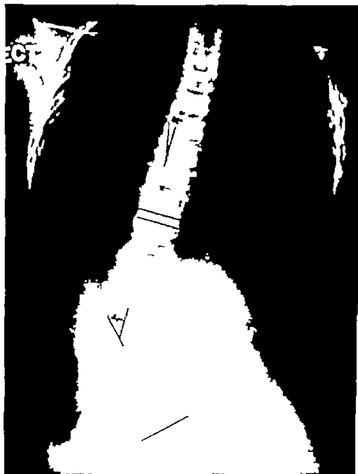


Fig. 288. Compensatory scoliosis. This curve necessarily starts at the lumbo-sacral junction and the convexity is towards the side of the short leg. There is no rotation.

necessarily starts at the lumbo-sacral junction (Fig. 288), whereas only congenital scoliosis ever does so amongst the structural curves. Compensatory scoliosis is almost invariably correctible and unfixed.

Tightness of one sternomastoid in long-standing torticollis produces a mild lateral curve of the cervical vertebræ.

Fibrosis from an empyema can produce a curve concave to the diseased side, rotation is present. It is now rarely seen.

Structural Scoliosis

This is the common and important group of curves and it is worth recalling that they are to be diagnosed by the presence of fixed rotation on forward flexion (Fig. 289) and structural changes in the radiograph, usually wedging of the vertebral body and rotation of spinous processes into the concavity

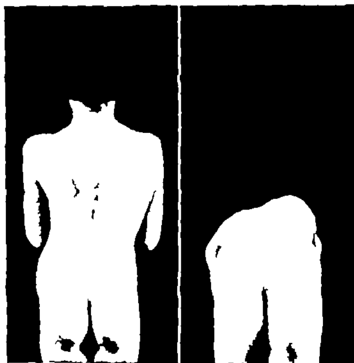


Fig. 289 Structural scoliosis. On forward flexion curvature and rotation persist and confirm clinically the presence of a structural curve.

CLASSIFICATION

Idiopathic	
Osteopathic	(1) Congenital (2) Other osteopathies
Neuropathic	(1) Congenital (2) Post poliomyelitis (3) Other neuropathies
Myopathic	(1) Congenital (2) Muscular dystrophy (3) Other myopathies
Thoracogenic	

Modified from Cobb's classification

Idiopathic Scoliosis

Ætiology Idiopathic scoliosis is a deformity of the growing child, particularly of girls. The cause is unknown. Such factors as sitting habits, posture, poor muscle tone do not on critical analysis seem related to the development of structural deformity. It has been suggested that poliomyelitis clinically unrecognized at the time is responsible. However there are considerable differences between the characteristic curves of paralytic and idiopathic scoliosis. Routine complete muscle charting of children with idiopathic scoliosis does not reveal isolated paralyses. The assumption that in so many cases unrecognized poliomyelitis has resulted in a residual paralysis of the spinal rotators only (muscles which cannot be clinically tested) is not easily tenable.

It is more probable that unknown metabolic or bone growth abnormalities will be found responsible.

Age of Onset. The onset of idiopathic scoliosis has always been regarded as occurring from 10–14 years of age. Whilst this is by far the commonest age group, idiopathic scoliosis occurs from infancy onwards. The peak ages of onset are from 6–18 months, 5–7 years, and 10–13 years of age.

In the thoracic or lumbar region a primary curve develops it will show rotation, vertebral wedging, and progressive deformity. A single curve causes imbalance compensatory curves develop, therefore, convex in the opposite direction so that the head is brought back over the pelvis. Failure to complete compensation results in a list. With a single primary curve there are compensatory curves above and below the only exceptions being in congenital and paralytic scoliosis where the primary curve may be so low that no room is available below for a compensatory curve. If two primary curves develop they are always found to adjoin each other and to have a compensatory curve above and below.

Curve Patterns. The site of the primary curve has been a useful key to the classification of the different types of this disease and the prognoses.

IDIOPATHIC SCOLIOSIS—CURVE PATTERNS

		Age at Onset
Thoracic	*Infantile*	Birth to 3 years of age
	Juvenile	Four to 10 years of age
	Adolescent	Ten years or over
Thoraco-lumbar		Rare before 10 years of age
Lumbar		Rare before 10 years of age
Combined thoracic and lumbar (double primary)		Common between 5–7 and after 10 years of age

Thoracic Idiopathic Scoliosis

It is in this segment of the spine that lateral curves are the most common and the most severe. There are as noted, three well defined groups based on the age of onset. The prognosis varies notably between the three.

Infantile Idiopathic Thoracic Scoliosis. In infants with scoliosis (excluding congenital and paralytic) the curves have remarkably similar characteristics. Such curves are

almost invariably thoracic and convex to the left in 90 per cent in contrast to adolescent thoracic scoliosis where the curves are to the right in 90 per cent. The proportion of boys to girls is approximately equal, whereas at a later age girls are more affected.

Such infants appear otherwise to be normal but as they grow they do so poorly and are often undersized, although there are no apparent endocrine disturbances. The



FIG. 790. Infantile idiopathic thoracic scoliosis. A grossly crippled undersized boy of 15 years. Radiographs at 18 months of age showed a 48 degree curve without congenital defects; the curve increased rapidly to 155 degrees.

curves progress rapidly and curves of 100 degrees are by no means uncommon within the first few years of life If the natural development of these curves is studied it will be found that almost all increase to more than 70 degrees of curvature and many to between 100–150 degrees. Although uncommon this type of scoliosis is one of the few remaining orthopædic causes of gross deformity (Fig. 290)

The early radiographs show no bony anomaly and there are no known ætiological factors. They do not, therefore, appear to differ from the idiopathic scolioses of later childhood.

Infantile Resolving Structural Scoliosis. A number of observers have noted the occasional spontaneous disappearance of a structural curve in an infant In the author's series twenty out of a hundred and twenty structural idiopathic infantile curves dis appeared Scott (1955) has employed the term "resolving structural scoliosis." It is obviously important to distinguish between curves which are so benign and the true infantile idiopathic where the prognosis is so very serious. The curve which may disappear is usually less than 20 degrees, the infant of less than 2 years of age, and there is little or no development of compensatory curves Occasionally there is seen a scoliosis with almost no radiographic lateral deviation but marked rotation these also resolve In the earliest stages it is often impossible to differentiate the two types.

The true frequency of this resolving curve is unknown, the figures given above are from a scoliosis clinic to which the more severe curves tend to be referred, they are probably much commoner than these figures suggest.

It is common to find marked moulding and facial hemiatrophy associated with either type of infantile curve.

Juvenile Thoracic Idiopathic Scoliosis. This age group is significant only in that it is intermediate between the more frequent infantile and adolescent cases. Curves are as frequently left as right, some 80 per cent of the children will develop curves of more than 70 degrees before the end of growth.

Adolescent Thoracic Idiopathic Scoliosis. This is the classical scoliosis, a girl in her early teens who has developed a right-sided thoracic curve The curves vary considerably in their progression and curves of more than 100 degrees have developed in less than 2 years in otherwise robust healthy girls, a remarkable phenomenon when it is realized that nothing is known of the cause. In a large series 50 per cent developed more than 70 degrees of curvature before skeletal maturation Thoracic curves may produce very ugly deformities with dropping of a shoulder evident rib rotation and prominence of the iliac crest (Fig. 291)

Thoraco-lumbar Idiopathic Scoliosis. Curves with their apex at the eleventh or twelfth thoracic vertebra have as might be expected characteristics of both lumbar and thoracic scoliosis. Rib rotation is a less important deforming feature the shoulders usually remain level but it is not uncommon for a prominent hip to be most disfiguring, even in a small curve (Fig. 292)

Approximately 30 per cent of these patients develop curves of 70 degrees or more It is rare for the curve to appear before the age of 10.

Lumbar Idiopathic Scoliosis. This very common curve is often so slight as not to be discovered until adult life. The shoulders remain level and as the ribs are not involved, rotation is not disfiguring The prominent hip is the main cause of unsightliness.

This curve which rarely appears before the age of 10 years has an almost invariably

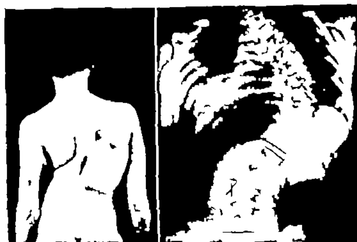


FIG. 291 Adolescent idiopathic thoracic scoliosis. A very typical example of this common and usually serious pattern of idiopathic scoliosis.



(*a*) (*b*)

FIG. 292 (*a* and *b*). Thoraco-lumbar idiopathic scoliosis. A slight curve of 45 degrees but showing the characteristic prominence of the hip which in this instance necessitated correction and fusion.

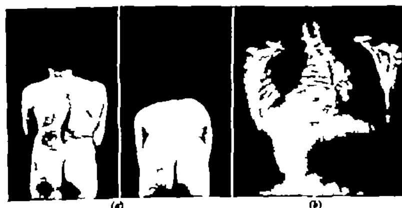
good prognosis, 90 per cent reaching the end of growth with less than 70 degrees of scoliosis. The excellent prognosis in degrees of curvature is equalled by the appearance of the children, who almost never require operation for cosmetic reasons (Fig. 293).



(*a*) (*b*)

FIG. 293 (*a* and *b*). Lumbar idiopathic scoliosis. Most of these curves are small and this patient shows the typical amount of deformity. The X-rays are already beginning to show osteoarthritic degeneration of the posterior joints.

The importance of lumbar idiopathic scoliosis becomes apparent in adult life. It is common for patients with this curvature to present themselves after the age of 30 with severe backache, this arises from a marked degree of osteoarthritis in the severely rotated posterior joints.



(*a*) (*b*)

FIG. 294 (*a* and *b*). Combined lumbar and thoracic idiopathic scoliosis. Both primary curves are 100 degrees, despite this the shoulders and hips remain level and the most noticeable deformity is the shortness of the trunk.

Idiopathic Combined Lumbar and Thoracic Scoliosis. The curvatures so far described have a single primary curve There is a large group in which on forward flexion two areas of fixed rotation persist, one lumbar one thoracic. Because these two curves on opposite sides balance one another the overall effect on the appearance is remarkably small

The two curves are commonly of the same degree but variations occur The prognosis relating to the appearance has already been noted to be good, equally so is it in degrees of curvature. Some 6 per cent of these patients develop primary curves of more than 100 degrees and even these whose radiographs look so disturbing show little deformity beyond a short trunk (Fig. 294).

The onset is common after 10 years of age but also from the fifth to seventh years. Occasionally a child diagnosed as having an infantile idiopathic thoracic scoliosis, particularly if it began between 18 months and 3 years of age, will after a few years of unusually slow deterioration, show the development of a fixed lumbar rotation and the true pattern is then revealed.

Prognosis. The prognosis of idiopathic scoliosis is related to the site of the primary curve the thoracic primary curves usually have a poor prognosis, the others less serious.

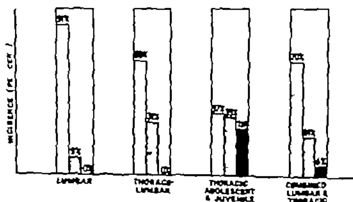


FIG. 295 A comparison of the prognosis in degrees of curvature of the four types of idiopathic scoliosis. Light shading—mild curves 0–70 degrees dark shading—severe curves 70–100 degrees black—more than 100 degrees.



FIG. 296. A photographic comparison of the same four types of idiopathic scoliosis lumbar thoraco-lumbar double primary and thoracic. Each girl has 70 degrees of scoliosis.

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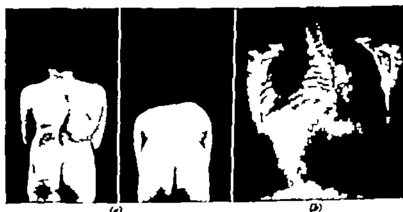

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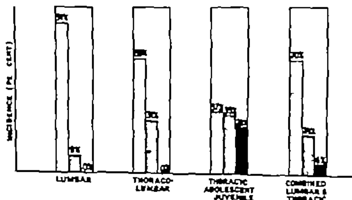


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FIG. 296. A photographic comparison of the same four types of idiopathic scoliosis lumbar thoraco-lumbar double primary and thoracic. Each girl has 70 degrees of scoliosis.

Subordinate to this fact but also important, particularly in the thoracic scolioses is the not surprising finding that the earlier scoliosis commences, the worse is the prognosis. Prognosis as discussed here has mainly been referred to as the degrees of curvature expected in the natural history of the developing curve however although this is important it is not the only factor since the degree of disfigurement varies considerably between the various patterns. The prognosis in degrees of curvature is summarized in Fig. 295 and the appearance of four girls with the same degree of curvature but different curve patterns compared in Fig. 296

Paralytic Scoliosis

Paralytic scoliosis develops only in growing children with a residual trunk paralysis. It is probable that the main factor is an imbalance between the right and left lateral trunk muscles however a symmetrical paralysis of the trunk muscles allows gravity to collapse the vertebral column, this is followed by the slow development of a structural curve. Although muscle paralysis and gravity seem to be the main and perhaps only factors it has been suggested that there are others. As a severely paralysed limb may show a decrease of bone growth, similarly this may be a factor acting on the concavity of the spinal curvature. Alternatively a fascial contracture of one side of the trunk may lead to the development of curvature.

The curves of paralytic scoliosis differ from those of idiopathic scoliosis in that they are longer and more mobile As will be seen the patterns of scoliosis also differ and there are in particular rib changes, not present in idiopathic scoliosis. In the radiographs, it is frequently possible to recognize curves as paralytic or idiopathic.

In a recent review of a hundred and ninety-three patients with paralytic scoliosis the following patterns of scoliosis were found

- High thoracic
- Thoracic
- Thoraco-lumbar
- Lumbar
- Combined thoracic and lumbar
- Collapsing or telescopic spine

It can be seen that most of the curve patterns are similar to those in idiopathic scoliosis. However the high thoracic curve is unknown in idiopathic scoliosis and the collapsing or telescopic spine is, of course seen only in paralytic curvature

High Thoracic Paralytic Scoliosis. These curves start at the first or second thoracic vertebræ The characteristic effect is a raising of the upper edge of trapezius by rotation of the first and second transverse processes on the convexity This causes an ugly deformity later becoming even worse when a cervical compensatory curve deflects the head away from the trunk (Fig. 297). It is very noticeable that the posterior angles of the ribs become razor edged, a characteristic of the paralytic thoracic scolioses Twenty patients in the series had completed their growth and the severe prognosis of this pattern is evident, for fifteen of them had curves of more than 100 degrees

Thoracic Paralytic Scoliosis. These curves much resemble the idiopathic type of curvature, both in appearance and prognosis It is a common curve, and it is found as expected with equal frequency in either sex, a finding which would be difficult to

understand if the cause of idiopathic scoliosis was unrecognized infantile paralysis, as girls are so predominantly affected by the idiopathic condition

There were thirty patients in the series who had completed growth and of these eight had curves less than 70 degrees, ten were 70–99 degrees and twelve were more than



(a) (b)

FIG. 297 (a and b). High thoracic paralytic scoliosis. The photograph shows the rotated first and second thoracic transverse processes. The radiograph shows the high thoracic curve with the dropped ribs associated with this scoliosis and probably due to the paralysis of the intercostals.



(a) (b)

FIG. 298 Paralytic thoracic scoliosis. In paralytic scoliosis owing to muscle weakness compensation is difficult and this boy is typical in this respect. He underwent correction and fusion at this stage.

100 degrees The prognosis, although bad, was distinctly better than the high thoracic curve (Fig. 298)

Thoraco-lumbar Paralytic Scoliosis. Many of these curves were very long. Although muscle imbalance plays the larger part we begin to see the effects of prolonged collapse

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70 degrees. Equally important but statistically more difficult to show was the prognostic effect of muscle imbalance in the lateral flexors of thorax or abdomen.

Paralytic scoliosis usually occurred within the first 2 years after poliomyelitis. However there were sporadic occurrences of curvature developing for many years afterwards the longest 12 years

Congenital Scoliosis

Congenital scoliosis is common and associated with bony anomalies, either an isolated hemivertebra, hemivertebræ, spina bifida, abnormal fusions, disc narrowings, rib fusions or absences, or numerous bizarre bony deformities

There are often associated cutaneous anomalies, additional hair angioma, dimples, or fatty tumours. In lesions of the lower spine it is common to find evidence of paralysis or sensory loss in the lower limbs.

There is great variation in the prognosis of congenital scoliosis. In general it is excellent, but in a small percentage the curve may become gross, so much so that perhaps the worst scolioses ever seen are those in children with congenital anomalies of vertebræ.

Scoliosis in Neurofibromatosis

In approximately 10 per cent of children who have Von Recklinghausen's neurofibromatosis there develops a lateral curvature of the spine This curvature is characteristically a very sharp curve in the mid-thoracic region almost always progressive



(a) (b)

Fig. 302 (a and b) Scoliosis in neurofibromatosis. The pigmented patches and the short curve are the characteristic features

of perhaps four or five vertebræ (Fig. 302). It may be assumed that the curve will increase rapidly perhaps developing a kyphotic element To det[illegible] the aetiology in scoliosis it is important to look for small areas of pigmentation, [illegible] common to find a few

café-au-lait patches sufficient to indicate that the scoliosis is neurofibromatous in origin and thus the prognosis is made clear

Myopathic and Neuropathic Scoliosis. In certain muscular dystrophies and commonly in such diseases as syringomyelia, Charcot Marie-Tooth neuropathy Friedrich s ataxia etc., bizarre forms of scoliosis may be seen, these particularly take the form of un balanced double primary curves. Whether the disease is in the muscles or in the nervous system, the importance of scoliosis is out weighed by the primary disease

The Diagnosis of Scoliosis

Children will be referred because they have a deformity of the spine It is first necessary to determine whether this deformity is a lateral curvature or an antero-posterior deformity kyphosis or lordosis. Having determined that there is a lateral curvature it is next essential to decide whether it is structural, postural, or compensatory When a child with a structural scoliosis flexes his trunk forwards there will be a per sisting lateral deviation of the spine with a fixed rotation of transverse processes and ribs (Fig 289). In a postural curve there is no such rotation and the curvature previously visible disappears on forward flexion, similarly in compensatory scoliosis due to a short leg, equalizing the legs by blocks removes all curvature. In structural scoliosis the ribs rotate with the vertebral body so that the transverse processes and the ribs are carried backwards on the side of the convexity and forwards on the side of the concavity Thus it is common for a child to present with a story that the mother has noticed either a posterior or an anterior deformity of the ribs, elevation or prominence of a shoulder scapula, or prominence of an iliac crest.

Having determined the presence of a structural scoliosis it is necessary to describe it. The essential part of the description is the number of primary curves and their site. A description of the degree of shoulder dropping, scapular prominence, jutting out of the iliac crests and rib rotation will give a mental picture of the degree of deformity present.

If possible, the ætiology should be determined. As paralytic scoliosis may be accompanied by very little muscle paralysis it is essential to carry out a complete muscle check so that isolated paralyses may be found and the true diagnosis established. Of equal importance is an adequate neurological examination, for not only is it common for scoliosis to be due to a primary neurological disease but scoliosis may produce secondary neurological changes, particularly if it is congenital. Finally a search is made for the pigmented patches of neurofibromatosis and skin stigmata of congenital scoliosis.

Leg lengths, both true and apparent are measured and the standing and sitting heights are recorded. It is probably true that scoliosis increases most rapidly during the periods of rapid growth and the recording of the sitting and standing heights at each visit is a useful routine

Thus in the initial examination the presence of a structural scoliosis and its ætiology is established. Thereafter all that is required is regular observation of the growing child until such time as growth has been completed or surgical intervention is considered necessary The child is seen at intervals of several months varying with the rapidity and severity of the curve s progress at each visit an erect antero-posterior radiograph is taken and the primary curve measured. The recording of the angle of curvature allows of objective assessment of the progress of the curve It also is a valuable check on any

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Having determined the presence of a structural scoliosis it is necessary to describe it. The essential part of the description is the number of primary curves and their site. A description of the degree of shoulder dropping, scapular prominence, jutting out of the iliac crests, and rib rotation will give a mental picture of the degree of deformity present.

If possible, the ætiology should be determined. As paralytic scoliosis may be accompanied by very little muscle paralysis it is essential to carry out a complete muscle check so that isolated paralyses may be found and the true diagnosis established. Of equal importance is an adequate neurological examination, for not only is it common for scoliosis to be due to a primary neurological disease but scoliosis may produce secondary neurological changes, particularly if it is congenital. Finally a search is made for the pigmented patches of neurofibromatosis and skin stigmata of congenital scoliosis

Leg lengths both true and apparent are measured and the standing and sitting heights are recorded. It is probably true that scoliosis increases most rapidly during the periods of rapid growth and the recording of the sitting and standing heights at each visit is a useful routine

Thus in the initial examination the presence of a structural scoliosis and its ætiology is established. Thereafter all that is required is regular observation of the growing child until such time as growth has been completed or surgical intervention is considered necessary The child is seen at intervals of several months varying with the rapidity and severity of the curve's progress at each visit an erect antero-posterior radiograph is taken and the primary curve measured. The recording of the angle of curvature allows of objective assessment of the progress of the curve. It also is a valuable check on any

treatment It was this failure in the past to measure curves which led to the continued employment of useless methods of therapy for many years (Fig. 303 Scoliosis chart).

At the initial visit the parents should be informed of the prognosis The parents of a child with scoliosis, particularly if a girl, are extremely anxious. A clear understanding of what is expected in the way of deterioration and the possibility of later surgical measures gives them an early understanding of the disease and then confidence may remain at a later date when a slight curve has become a severe one.

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SCOLIOSIS CLINIC

FIG. 303 A useful recording chart for the angle of curvature.

Radiology Radiography in scoliosis is important, not only in determining whether there are congenital vertebral anomalies, wedging secondary to structural changes, abnormal rib position etc., but because the degree of curvature can only be accurately determined on the radiograph. This should cover the whole length of the thoracic and lumbar spine and include the iliac apophyses, a 17 × 14 in. film is used. The radiograph may be taken either erect or supine but it is preferable to use one or the other routinely and probably erect is the best At the initial examination a lateral view is valuable as it may reveal some unexpected kyphosis or congenital anomaly Using a standardized technique the erect antero-posterior film taken at intervals provides a means of observing the progression of a curve

Measurement of the curve is made by the method of Ferguson or Cobb In Cobb's method lines parallel to the upper border of the uppermost vertebra and the lower border of the lowest vertebra of the primary curve are drawn. From these lines perpendiculars are erected and the angle of this intersection is the angle of curvature. Where these two lines cross there are two pairs of angles. The one to be measured is that which will increase with the increase of curvature. This seems obvious but when the curvature is approaching 90 degrees it may be difficult to determine which angle to measure.

It is only necessary to record the primary curves, identified clinically the upper and lower vertebræ of which are determined as follows. If the apex of the curve is studied it will be seen that the discs are widened on the convex side, this becomes less until at the upper and lower borders of the curve there is a disc which is neutral, that is of equal width on both sides. The discs respectively above and below the neutral discs will be in the next curve and will be open on the opposite side. The lines are drawn parallel to the upper and lower borders of the vertebræ adjacent to the neutral disc. It not infrequently happens that there is no neutral disc, since none is found of equal width on both sides. Under these circumstances there will be found a neutral vertebra, that is a vertebra with the disc below widened to one side and the disc above open to the other This neutral vertebra is in both curves and when measuring the lower curve the upper border of the neutral vertebra is used, and for the upper curve the lower border

The Pathology of Scoliosis. The skeletal pathology of scoliosis is confined to structural alterations in the vertebræ and ribs In the early stages these structural alterations are not very apparent, but the skeleton of a severe long-standing scoliosis will show remarkable changes.

The rotation of a thoracic vertebra carries with it the rib so that on the convexity the ribs are carried posteriorly and on the concavity forwards, and the ribs on the concavity will tend to be crowded together The vertebral bodies will be wedged and narrow on the concavity the laminæ on the concavity are often narrow and of considerable density Associated with the structural changes in the vertebral bodies is the development of an obliquity in the pedicles and laminæ well seen in a dried scoliotic skeleton.

With these osseous changes there are necessarily shifts of the mediastinal structures, these are complex and their physiological importance ill understood. In the severe scoliotic there is a reduction in vital capacity and it is reasonably certain also a reduction in the life expectancy from inadequate function of heart and lungs.

Treatment

Conservative. The conservative treatment of scoliosis has changed little over many years and has been based on two main principles. Firstly despite lack of proof it has been believed that idiopathic scoliosis is due to muscular imbalance, that the muscles on the convexity were weak, those on the concavity normal. It seemed logical that exercises designed to develop the weak muscles of the convexity would not only slow up progression of the disease but might even improve it. Asymmetric systems of muscle exercises, therefore, have been devised by many surgeons and have been supervised for many years by devoted physiotherapists. As a result of such exercises the patient may be induced to hold himself more correctly if less naturally with an apparent improvement in the scoliosis in a number of cases however the curvature in the radiograph does

not lessen. If in fact there were a weakness of muscles on one side as there is in paralytic scoliosis, it is doubtful whether asymmetrical muscle exercises would bring them up to the strength of the concave muscles

Since muscular exercises only make the child stand better it is very dubious if they have a place in therapy It must be remembered that treatment by exercises interferes very considerably with education, as the child will have to be absent from school once or twice a week for several years. If the mother has other children, or goes out to work, it may cause considerable domestic or financial difficulty and the performance or non-performance of them a frequent source of friction between mother and child.

The second principal method of conservative treatment of scoliosis has been a mechanical support to overcome the effect of gravity Such mechanical support has been devised in many ingenious ways. A support may be given to prevent deterioration of a curve or after an initial correction obtained by mechanical methods, in the hope of holding correction. Numerous spinal braces in metal and leather some with correcting devices have been invented. Equally ingenious have been the variety of plasters which have been applied and used for correcting or maintaining curves, often requiring frequent changes and much hard work on the part of the surgeon and the patient. Less rigorous methods have been those such as lying in bed for certain periods of the day or a plaster bed at night, an attempt to avoid the effect of gravity or to provide correction during periods of recumbency It is possible in idiopathic scoliosis that total recumbency during the remaining growth period would prevent an increase.

In assessing methods of conservative treatment it is essential to be objective. In 1941 the American Orthopædic Association published the results of a thorough and lengthy review of the results obtained in several scoliosis clinics in the United States. In brief it may be said that conservative treatment failed to improve the curves except in a very small percentage and then only by a few degrees, rarely more than the variation in accuracy of measurement. Conservative treatment by exercises or brace, therefore, has been conclusively shown to be ineffective in improving curvature.

Two exceptions to this condemnation of conservative treatment must be mentioned. Stagnara of Lyon has demonstrated that a formidable programme of initial corrective plaster splintage followed by about 18 months of continuous plastering and bracing, accompanied by a most vigorous regime of exercises, has allowed of some correction and maintenance of correction in a brace Associated with this there has been a partial correction of rib rotation, one of the main deforming features However such treatment requires the child to be in hospital for 2 years. It is too early to say whether the maintenance of correction that he has demonstrated will be held after all bracing is left off

Previously spinal braces have relied on pressure on the trunk. Blount of Milwaukee devised a brace which incorporates a new principle. There are pelvic and mandibulo-occipital rings connected by sliding bars, and by distracting the two units it is possible to stretch the trunk. Although it is early yet to assess the final value of this method a review of the present position will be valuable There have been at the Royal National Orthopædic Hospital some fifty children treated by the Milwaukee brace The indication for its use has been a rapidly progressing curve in a child too young for operation. The longest period for which the brace has been applied is 3 years. To the present there have been no instances in which a scoliosis is worse than when the brace was applied and many are holding from 10–40 degrees of correction. This is an event not in accordance with

the natural progression of scoliosis The Milwaukee brace as can be judged from the photographs (Fig. 304) is difficult to wear and perhaps one likely to disturb a sensitive child. It is quite remarkable, however how well it is tolerated by the child and the parents.

Mandibular changes may be induced in a minority of cases and in a plaster distraction jacket embodying the same principle and used in pre-operative correction on

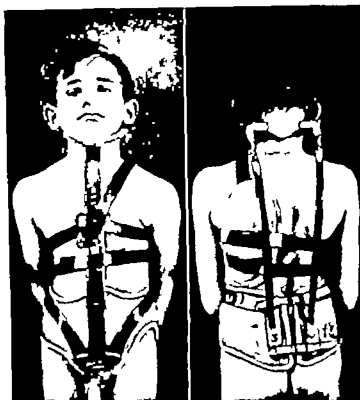


FIG. 304 The Milwaukee Jacket.

several occasions, protrusion of the upper front teeth has been noted this, however is easily corrected by the dentist.

The regime of management advocated, therefore is one of serial observation of the child. The purpose of this is to discover the curve which is progressing to a point where correction and fusion by surgery is necessary and worthwhile. This may be anticipated by a knowledge of the prognosis of the various patterns and types of scoliosis. Thus it is that great attention has been paid in this chapter to the prognosis of the various patterns. However within each pattern there is always considerable variation and in some patterns only a very small percentage of curves become serious and these cases are impossible to identify early

It is difficult to estimate when a child has ceased to grow for although the normal age for a girl to stop is fifteen, and for a boy seventeen, there is a great individual variation

in skeletal maturation. Risser noted that when the iliac apophyses which first appear anteriorly grew along the iliac crest and dipped down to the posterior superior spine there was no increase in idiopathic scoliosis thereafter (Fig. 305). It is presumably because this is contemporaneous with the cessation of growth in the spinal epiphyses. In practice the maturation of the iliac apophyses is most valuable for it gives us an indication of the end of curve progression.

Indications for Surgery The aim of correction and fusion is to reduce deformity or to stabilize an immature curve which threatens to become a severely deforming curve if not treated surgically

In the mature curve that is a curve in a patient with completion of the iliac apophyses, the indications for operation are clear First, it is necessary to consider what can be



FIG. 305. The iliac apophyses have grown to the posterior superior spines and turned down on one side and fused with it. This is the appearance described by Risser which coincides with the stoppage of spinal growth.

achieved by correction and fusion. A dropped shoulder can be elevated, a prominent iliac crest can be covered by reduction of the curve the rib rotation, which is often the main deformity will not be affected. Occasionally shortness of the trunk is the important deformity and in a very good correction it is possible to help this but it is rarely by itself an indication for operation. One can assess in a child with a severe but mature deformity how much the raising of a dropped shoulder or the covering of a prominent hip would improve appearances If it would not decrease the deformities, then despite the severity of the curve, surgery should not be advised. Full consideration of the child's and of the parents wishes must be taken in making a decision.

The correction of mature curves may be difficult for they may be rigid and the rib rotation which is often the worst feature of the deformity cannot be altered. As with other orthopædic deformities the theoretical advantages of earlier operation before deformity occurs are very considerable It would be mistaken, however to think that a majority of scolioses require operation for it is probably no more than 5–10 per cent of idiopathic curves and perhaps 30 per cent of paralytic curves which are severe enough for operation, the others are left untreated. It is in this consideration that the prognosis of individual curves is so important. As earlier discussed, the prognosis of idiopathic and paralytic curves can be related to various factors such as the age of onset of curvature and of poliomyelitis and of the site of the primary curve. Within each group there will be considerable individual variation but the overall prognosis of the pattern is of great value in indicating whether surgery is likely to be necessary or not. For the individual patient the degree of curvature at a young age, the rapidity of deterioration etc., are all prognostic factors which encourage surgical interference

Surgical correction and fusion of the immature curve is, therefore advocated so that in those cases where the prognosis is poor stabilization is achieved before gross deformity occurs.

In idiopathic scoliosis the curve most often needing correction and fusion is the thoracic, particularly if starting in infancy or before the age of 10 Thoraco-lumbar curves may occasionally need operation because of the prominence of the hip which is a marked feature of this pattern It is probable that lumbar scoliosis never needs correction and fusion for cosmetic purposes. In a very small percentage of those with double primary curves, correction is indicated. The deformity in this curvature is one of shortness of the trunk and correction will not decrease this by much nor affect the rib rotation, the only other deforming feature. In the double primary idiopathic scoliosis, therefore, it is particularly difficult to estimate the time and need for operation but for a patient of 10 11 or 12 years of age who has primary curves of more than 90 degrees prophylactic correction would be indicated.

In paralytic scoliosis the majority of high thoracic paralytic curves require correction, particularly noteworthy in this type of curve is the raising of the upper border of trapezius by the rotation. As this is the main deforming feature and as rotation is not affected by operation, the time at which a high thoracic curve is to be operated upon should be so designed that this will not mar the final result excessively In thoracic, thoraco-lumbar and lumbar curves, the indications will be frequent and dependent upon the degree of deformity presented or expected In paralytic scoliosis, however due consideration must be given to back-ache, tiredness of the back, instability of the back or the need to get rid of cumbersome splintage factors which are often important and may indicate operation in a child with only moderate deformity

In neurofibromatosis, curvature is almost invariably progressive and very frequently fusion is indicated

No reliable information is as yet available as to how early fusion may be safely performed. It has been the author's policy to wait until 10 years of age, others feel no such restriction, yet other surgeons await the end of growth. It is to be borne in mind that elsewhere in the body deformities are difficult to control in the growing child, there is some evidence nevertheless, that fusion in growing children is a valuable procedure, and preferable to waiting until growth has stopped.

Surgical Treatment

Correction. Fusion of the spine was first performed by Hibbs for tuberculosis, and it was not long before he applied it to scoliosis Risser who was then working at the same hospital devised the hinging jacket now known as the Risser jacket. This is the basic correcting plaster jacket for scoliosis. An alternative method of correction is by a hammock, in which the curve is first stretched, followed by the application of a plaster as devised by Lemesurier of Toronto In more recent years, the Milwaukee jacket developed by Walter Blount has been used.

The Risser jacket is suitable for curves in the lumbar thoraco-lumbar and lower thoracic regions. Where there are two primary curves a kyphosis or the curve is high in the thoracic region, as in paralytic scoliosis, the Risser jacket is of no value as the hinging axis is too high and comes across the axillæ. Under these circumstances, the

distraction jacket as devised by Stagnara and which in principle is exactly the same as the Milwaukee jacket has proved of value.

A primary curve is usually rigid and total correction only rarely possible. The rigidity of the compensatory curve does also have to be considered. If total correction of the primary curve is achieved the compensatory curves must be fully mobilized by the patient's own corrective efforts, otherwise curves in the opposite direction to the primary would remain. It is rare for the combined rigidity of the compensatory curves to be as much as the final possible correction of the primary. However, to avoid over correction of the primary curve in relation to the compensatory curves, the rigidity of these latter curves must be measured. The erect patient bends fully to the side which will correct the compensatory curves and a radiograph is then taken. The residual compensatory curves are then measured, added together and correction of the primary curve should not be to an angle of curvature less than their total.

The correcting jacket either hinging or distracting is applied after ample felt padding has been applied to pressure points. Methods which employ distraction to the supine patient or correction of the compensatory curve by applying the jacket to the bent patient are used by many. Application of either type of jacket to the erect patient ensures an accurately fitting jacket and is a simpler technique. In the Risser jacket the leg on the side of the convexity is included to the knee (Fig. 306).

In recent years Risser has used the localizator jacket in which local pressure to the convexity is applied as well as distraction.

Correction should be slow and guided by the patient's comfort, it will usually require from 2–6 weeks. Pressure sores may arise from a badly fitting plaster, too rapid correction or attempted over-correction. Sores are rare, usually preventable but must always be sought during this stage. Correction is carried to the angle allowed by the compensatory curve rigidity or if this is not achieved until the patient becomes tightly wedged or commences to be drawn into the jacket.

When the maximum possible correction has been achieved the deficiency in the jacket is filled in and a window cut posteriorly over the area of spinal fusion. The operation is carried out through this window.

Spine Fusion. Numerous modifications of this operation have been practised, most are varieties of Hibb's technique. Bone bank bone has allowed extensive fusions in young children. It is usual to fuse the convex and concave sides of the curve. The extent of fusion is the full length of the primary curve as defined by widened discs or rotated spinous processes. Transfusion is almost invariably necessary and the operation must be regarded as a major procedure.

Subsequently the patient is kept in bed in the correcting plaster for 6 months, some surgeons allow a shorter period. The patient is then mobilized in a spinal support. One year after operation the graft can be regarded as consolidated.

Results

The correction and maintenance of correction of scoliosis has proved a very difficult problem. There is an average loss of 25 degrees from pre-operative correction. Pseudarthroses occur in a number of patients and may lead to a total loss of correction; they are perhaps more common with bank bone. If maintenance of good correction is used as the criterion approximately 50 per cent of patients achieve good or excellent

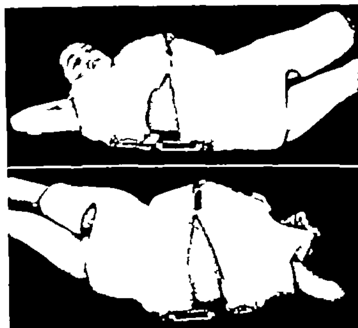


FIG. 306 (*a*). The Risser hinging jacket. The leg on the convexity is in plaster the anterior and posterior hinges are placed well laterally

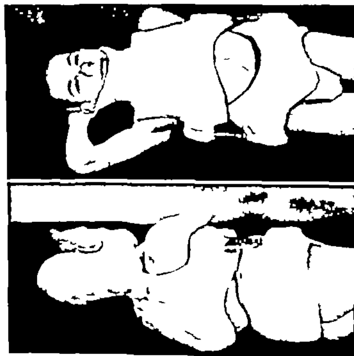


FIG. 306 (*b*). The distraction jacket.

results. Following operation in the growing period approximately 75 per cent maintain the pre-operative curvature including the 50 per cent who hold worthwhile correction. Thus fusion has prevented the curvature increasing in 75 per cent and half appear to have benefited from the correction. These percentages are based on a short term follow up of 1–6 years and they give no more than an impression of the results (Fig. 307)

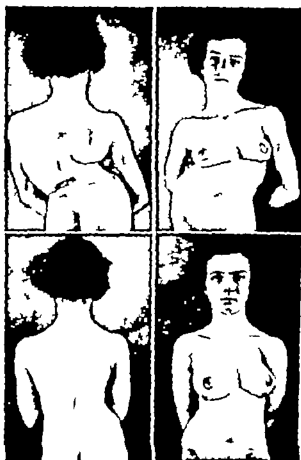


FIG. 307 Correction and fusion. Photographs pre- and post operation, of a girl with paralytic scoliosis, corrected from 133 degrees and maintaining curve of 80 degrees after 3 years

Spinal Osteotomy Roaf has utilized lateral spinal osteotomy for correction of curves. This procedure is not without risk and has to be followed by spine fusion at a second stage. The indication is to be restricted to those patients in whom the curve is otherwise incorrectible

Correction by a Retained Jack. Allen devised and used a metal jack inserted across the concavity between the two ends and forcibly opening the curve at the time of operation Unfortunately curves cannot be corrected to less than 70 degrees by this method.

Stapling. Staples modified from those devised by Blount for epiphyseal arrest in the lower limbs have been used in scoliosis by Nachlas and others. They are placed on the convex side of the vertebral bodies of the primary curve. The method is still under trial but present results are not very encouraging.

Thoracoplasty Correction and fusion results in no improvement of the rib rotation. Removal of the posterior portions of the projecting ribs on the convexity should improve



FIG. 308 (*a*). "Silhouette" X-ray in scoliosis suitable for thoracoplasty



FIG. 308 (*b*). "Silhouette" X-ray in scoliosis in which the vertebræ are rotated against the ribs.

the patient's appearance, this has been tried previously on many occasions but the operation has never found great favour The reason is that in severe scoliosis, particularly paralytic, the vertebræ are so severely rotated as to be touching or close to the ribs of the convexity Removal of the ribs, therefore, does not decrease the deformity as the vertebræ and transverse processes project backwards as much as the ribs. There are, however some cases in which a small but worthwhile improvement is obtained by this simple procedure

It is useful to distinguish those in whom vertebral rotation is extreme from those with less rotation and suitable for thoracoplasty This has been achieved with considerable accuracy by a "silhouette" radiograph. This is taken with the patient bent forwards and a silhouette of the rib hump is then X-rayed. In Fig. 308 (*a*) there is a gap between the ribs and the vertebral bodies, whereas in Fig. 308 (*b*) there is no such gap and it is

unsuitable for thoracoplasty The operation involves the removal of about 3 in. of rib from the tip of the transverse process outwards and usually five to six ribs have to be excised The operation is not a major procedure

Antero-posterior Deformities

Excessive posterior curvature, kyphosis or forward curvature, lordosis may like lateral curvature, be postural or structural. The postural varieties of abnormal kyphosis and lordosis are common. In the spine there is a normal thoracic kyphosis and a lumbar lordosis. Abnormal exaggeration or decrease of these angulations is commonly seen as a postural defect.

Because the spine rests on the pelvis, undue forward or backward pelvic inclination will alter the antero-posterior angulations of the spine just as a short leg may produce a compensatory lateral curvature. Wiles has classified the postural abnormalities of the back as follows

- Lumbar lordosis
- Sway back
- Flat back
- Round back

Like most postural defects these curves are easily correctible and becomes corrected as the child matures in a boy when athletic prowess becomes important and in a girl when interest in her appearance develops. Treatment other than by encouraging general play and activity is unnecessary

Structural Kyphoses

Adolescent Kyphosis. In the adolescent child, 12–16 years of age, a roundness of the lower thoracic spine may be noticed at routine medical inspection or pain may call attention to it. It is frequently associated in boys with their first regular heavy physical work, this may be because pain is caused in a pre-existing adolescent kyphosis. The kyphosis is round and gradual, unlike the angular kyphoses of tuberculosis, there is an associated lumbar lordosis (Fig. 309)

The kyphosis is permanent and incorrectible a radiograph will show slight wedging of several of the lower thoracic vertebral bodies in the milder cases, in more extreme cases of so-called Scheuermann's osteochondritis there are gross wedging, irregularity of the vertebral epiphyses and perhaps herniation of the disc through the epiphyseal ring. Lambrinudi regarded "congenital" tightness of the hamstring muscles as an aetiological factor Because the patient cannot freely flex the hips when touching the toes, forward flexion could only be accomplished by excessive flexion of the spine and this produced epiphyseal injury

Adolescent kyphosis is a difficult condition to treat because it is common and not very serious Adequate treatment necessitates the patient lying in a plaster bed day and night during the growing period, which may of course extend over some years if the kyphosis appears early this is not practicable Treatment by exercises and a support in the ambulant child is probably of no value although the Milwaukee jacket is theoretically useful Fortunately it is only rarely that the kyphosis produces an ugly

deformity and the vast majority require no treatment. Heavy lifting and stooping should be avoided until the vertebral epiphyses are fused.

In a number of patients there is pain in adult life, and this is frequently in the lumbar lordosis compensatory to the fixed thoracic kyphosis.

Kyphosis and Kypho-scoliosis. The term kypho-scoliosis has been much employed but it is an uncommon condition. When a vertebral body is absent or wedged it is not uncommon to find the development of a kyphosis as growth proceeds. If with this wedging, fusion, or vertebral absence growth is asymmetrical one limb of the kyphosis



FIG. 309 The clinical and radiological appearances of typical structural adolescent kyphosis.

may rotate and produce a kypho-scoliosis. Thus it is that the commonest cause of kypho-scoliosis is a congenital anomaly of the vertebral bodies. These anomalies occur most frequently in the upper thoracic region and at the junction of the thoracic and lumbar vertebræ. Congenital kyphosis or kypho-scoliosis in these areas may be very rapidly progressive in the early teens and produce severe deformity.

Although congenital anomalies which may lead to kyphosis are common, by no means all vertebral body fusions, wedgings etc., lead to conspicuous deformity. If such a deformity is observed in a young child it should be seen at frequent intervals. If the kyphosis increases, fusion should be proceeded with.

Congenital kypho-scoliosis can cause a very ugly deformity and it is difficult to correct. A distraction jacket followed by fusion may lead to a small improvement. As correction of such a deformity is so difficult, incomplete prevention by an early fusion is advisable. It is particularly difficult to obtain successful fusion at the apex of a kypho-scoliosis.

Paraplegia in Kypho-scoliosis

It is not uncommon for paraplegia to develop in kypho-scoliosis due to a congenital anomaly. This paraplegia, although it may occur in the young, frequently develops at the end of growth, and a number have been seen at this period. The paraplegia is due to an anterior ridge of bone over which the spinal cord is stretched, this may be accompanied by dural tightness. Attempted correction of a kyphosis with congenital vertebral fusion does not lead to relief of the paraplegia. Since the stretching agent lies in front, antero-lateral decompression would seem to be a logical form of treatment. Unfortunately the removal of dense bone from the vicinity of the spinal cord is a hazardous procedure in which thrombosis of the spinal arteries may lead to permanent paraplegia. The alternative procedure of laminectomy and incision of the dura may result in a recurrence of paraplegia after a year or two due to an increase of the kyphosis secondary to instability incurred by the extensive laminectomy necessary. Dewar of Toronto who has had very considerable experience of paraplegia in scoliosis has found incision of the dura a satisfactory procedure, not followed by recurrence, and it may yet prove that our recurrences were exceptional. Although the optimum method of dealing with a paraplegia in kypho-scoliosis is at present uncertain it would seem that the safest approach may be laminectomy with incision of the dura followed immediately or at the earliest sign of recurrent paraplegia by a transthoracic anterior vertebral body fusion.

True kyphosis is occasionally seen in idiopathic scoliosis but only in the severest of the infantile idiopathic thoracic group. It is unaccompanied by paraplegia.

In neurofibromatosis the scoliosis may be associated with a kyphosis and with paraplegia. This is due either to a neurofibroma or a lateral meningocele in the thoracic region.

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CHAPTER XVI

ANOMALIES OF THE SPINE

LAWSON DICK

The human spine is a part of the skeleton upon which the assumption of the orthograde posture in man has imposed severe stresses unknown amongst mammals who remain quadruped. It is, therefore, not surprising that disorders in the spine are common. These are often due to changes induced by wear and tear but they may also be due to developmental abnormalities, errors of growth and ossification, or to non-specific infective lesions of the joints.

A typical vertebra develops from three primary ossific centres in the fœtal cartilaginous anlage which forms around the primitive notochord There is one large primary centre for the body and two primary centres, one on each side of the neural tube form a complete neural arch, and join to the bodies in the period from the eighth month of fœtal life to about the tenth year of post-natal life. This fusion begins at the cephalic end of the spine and finishes at the caudal end It is for this reason that anomalies due to failure of fusion of the arches are most commonly seen in the lumbo-sacral region. If the mesenchymal defect, which is the reason for this failure, is severe enough to affect the spine at the upper level, the fœtus usually cannot develop to a stage at which independent existence is possible

Five secondary ossific centres complete the ossification of each vertebra. Three form the tips of the transverse and spinous processes. The bodies of each vertebra are completed by the ossification of two ring-shaped epiphyses, forming their upper and lower margins. These epiphyses all appear about the age of puberty and fuse at about twenty years.

Two forms of joint link the vertebræ. The facet articulations are simple diarthrodial joints having a joint capsule, articular cartilages, and a joint cavity The intervertebral articulations—the joints between the vertebral bodies—are more complex. The cartilaginous precursor of the spinal column forms around the notochord. As the spinal column develops it becomes segmental and separate cartilaginous precursors of inter vertebral bodies are formed. These in time replace the notochord completely but in the intervals between them remnants of notochordal tissue remain. They are enclosed by rings of fibro-cartilage, and the whole structure so constituted becomes the inter vertebral disc. The intervertebral central joints are, therefore synchrondroses and do not possess a joint cavity

CONGENITAL ABNORMALITIES

These are of importance only if they cause functional disability save for the few instances in which they may be of medico-legal significance. Thus two vertebral bodies may be fused into one large bony mass. This developmental error is seen most often in the cervical and the lumbar regions. It is not responsible for any disability It may occasionally be of importance to differentiate the congenital condition from secondary

fusions due to trauma or to infection. The distinction rests upon the recognition of the regularity of the shape of the fused vertebræ seen in radiographs. The general outline of the spine is normal There is no evidence of bone destruction or distortion, and there is no formation of reactive new bone. The radiographic shadow is simply that of a vertebral body twice as deep as normal.

The number of the vertebræ in the various segments of the spine may not conform to the normal pattern. There may be only six cervical vertebræ or more commonly eight. The number of the thoracic vertebræ seldom varies from twelve but not infrequently there may be six lumbar vertebræ. The extra lumbar vertebra may be truly additional, or it may be a first sacral vertebra that has not fused with the other four to form the body of the sacrum, but remains separate and articulated. When there is an eighth cervical vertebra it often carries an extra rib—a cervical rib—and this may cause disability (pages 565–6). The transverse process, on one or on both sides of the first lumbar vertebra, whether it be an extra vertebra or not, may not fuse but may develop as a separate articulated structure and may be large enough to have the appearance of an extra rib. This condition never causes symptoms, but the question may arise whether it is due to trauma. There may be similar diagnostic difficulty if the epiphyses of the tips of the lumbar transverse processes do not fuse—is this, for example, due to unhealed avulsion fractures? If there is a history of trauma, it may not be possible to give a categorical answer to these questions, but two points help in arriving at a decision Fractures of a lumbar transverse process are very rarely almost never bilateral failure of epiphysial fusion is commonly so. The shadows of the adjacent edges of the gap in the bone are much less regular in avulsion fractures, even when these are of long standing, and the regular edges of the unfused epiphysis are demarcated by the dense shadows of the cortical bone of their margins as the edges of fracture lines are not There are other developmental anomalies of the spine which are not accompanied by functional disability but the above are those most commonly seen. When they are accidentally discovered in the course of routine examination they should be disregarded Those which are next discussed may cause disability and often do and may require treatment.

Congenital Hemivertebra

One half of the primary ossific centre of the vertebral body may fail to appear together with the primary centre for one half of the neural arch This produces the condition of hemivertebra. It commonly affects two or three adjacent vertebræ, and is the cause of gross and intractable congenital scoliosis or kypho-scoliosis. There are also other deficiencies in the associated myotome and, in the thoracic spine, for example, one or more ribs are missing, with a consequent defect in the chest wall.

There is no known method of treating this complex deformity These children are usually of poor general physique, may have other congenital defects, for example in the cardiovascular system, and usually succumb early to some intercurrent illness.

Sacralization and Hemi-sacralization of the Last Lumbar Vertebra

The transverse processes of the last lumbar vertebra do not normally articulate with the sacrum. If there is an additional lumbar vertebra, its transverse process not uncommonly articulates with the posterior end of the iliac crest just below and in front of

the posterior superior iliac spine One or both transverse processes of an otherwise normal fifth lumbar vertebra may be abnormally large and have this abnormal contact with the pelvis.

When the sacralization is bilateral the condition seldom causes trouble, is usually found incidentally and can be disregarded. Sometimes, however the false joint becomes osteoarthritic and gives rise to low back pain which may be severe. This is more liable to occur when only one transverse process articulates—the condition known as hemi-sacralization. The pain is referred to the lumbo-sacral region and does not radiate into the lower limbs it may be felt in the upper inner quadrant of the buttocks, but it does not extend down the thighs It is increased by exertion and by stooping, and is usually worse towards the end of the day There is commonly no spasm of the posterior spinal muscles, and movement of the spine is usually not impaired There is acute tenderness on pressure over the false joint or joints. The diagnosis is established by radiography

The *treatment* is to protect the affected false joint of the spine from stress. This may be done by a change of occupation Such a change is not always feasible, but if it can be effected nothing else may be needed A lumbo-sacral belt or corset may be provided. This consists essentially of a firm canvas belt about 10–14 in. in depth secured in front by several strong canvas straps with buckles and reinforced behind with a firm plate or rectangular frame of malleable metal moulded to the contour of the back. Short wave diathermy or some similar form of physiotherapy may give temporary ease but cannot effect any permanent betterment remedial exercises are important for the postural musculature

If conservative measures fail to give relief from the pain, operative treatment should be considered. In assessing whether this is necessary however it must be borne in mind that the condition is benign, and even if untreated would never shorten life or impair general health. A decision must be reached purely on the grounds of how much the pain means to the patient The surgeon should explain these facts and what the operative treatment and the necessary after-care entail. The final decision about operation must be left to the patient. The only dependable operation for the relief of the pain is posterior fusion of the fourth and fifth lumbar vertebræ to the sacrum. Methods of direct attack on the false joint have been described but none of them is certain and all are difficult. Operative lumbo-sacral fusion necessitates a tedious period of after-treatment, but the operation, though it is time-consuming, is not inherently difficult and with care fusion can be obtained with a fair degree of certainty

Lumbo-sacral Fusion

A full-length plaster bed is made, extending from the shoulders and the base of the neck to the ankles. After it has been padded and mounted on a frame and its fit is confirmed, the patient is given a week or so to settle and to become accustomed to it. The operation is not undertaken until the patient is comfortable and confident in his bed, in which he will have to spend 3 months.

Operation. The patient lies prone on the operating table with a small sand bag under the symphysis pubis. The exact contour of the spine during the operation is not important because the fusion is produced by the use of cancellous bone chips and not a cortical transplant. The post-operative contour of the spine is determined by the plaster bed

the sand-bag under the pubis during operation facilitates access to the lumbo-sacral region and, if necessary to the posterior end of the iliac crest.

A vertical incision is placed over the fourth and fifth lumbar spinous processes and the upper part of the sacrum. The hæmorrhage accompanying clearing of the muscles from the spinous processes and the backs of the neural arches is much reduced if the subsequent dissection is carried out with a diathermy needle. In addition, as the muscle is finally cleared laterally with a broad osteotome, gauze swabs are firmly packed into the space as each portion of muscle is mobilized Thus firm packing at the same time completes the dissection and controls the hæmorrhage Radiographic localization is not needed, as the back of the sacrum is an easily recognizable landmark. When as much of the dorsal aspect of the spine as is needed has been thus exposed, the gauze swabs are removed and the muscles are held aside with self retaining retractors. The interspinous ligaments are excised down to the ligamenta flava. By the use of an osteotome or a chisel the sides of the spinous processes and the backs of the neural arches are decorticated and the underlying cancellous bone is exposed. The dorsum of the sacrum is prepared in a similar manner The rawing of the neural arches should be carried out as far as the facet articulations, which should be opened and excised and the opposing surfaces fragmented. The final step in preparing the bed for the graft is to split the spinous processes longitudinally and then to cut them up into small fragments without actually detaching these fragments completely turning them up and down so that they are in contact with their neighbours. A wide raw area is thus made ready to receive the bone transplant.

The best type of transplant for lumbo-sacral fusion is cancellous bone in chips of about 0·5 cm in diameter If these can be obtained from a bone bank, the operation time is considerably reduced. If bank bone is not available, an abundant supply of cancellous chips can be obtained from the posterior crest of the ilium. A small curved incision is made over the iliac crest extending upwards and forwards from the posterior superior iliac spine. The spine, the posterior end of the crest, and both surfaces of the posterior end of the wing of the ilium are cleared of periosteum. This clearance should be made very thoroughly before the bone itself is cut. As the muscles are stripped from the posterior surface of the ilium, the periosteum should be elevated with care lest the superior gluteal artery be injured in the greater sciatic notch If this accident does occur the resultant hæmorrhage may be very difficult to control. A block 2 in in length by 1 in in depth and including the posterior superior iliac spine is cut out of the posterior iliac crest. While an assistant cuts this into chips of a suitable size, more cancellous bone can be gouged out from the depths of the ilium itself Ample bone can almost always be obtained from one crest, but there is no reason why both crests should not be used if necessary These chips are packed into the rawed bed on the backs of the sacrum and the lower two lumbar vertebræ. Suture of the posterior spinal muscles over the transplant holds it in place the muscles are sutured over the donor area in the ilium and the wounds are closed. Bleeding is not excessive if this technique is carefully followed, but some blood loss is inevitable and the operation is not a short one. It is, therefore desirable to give a blood transfusion usually 1 pint during the operation and 1 pint after return to the ward is enough.

The plaster bed is placed on the patient and he is gently rolled on to his back. The use of a turning shell makes it possible to nurse the patient on his face or on his back as

is desired, and makes the pressure points accessible to nursing care. Immobilization in a plaster bed should be continued for 12 weeks Thereafter a short plaster spica is applied—a short plaster jacket with an extension down one thigh to above the knee but not so far as to impede flexion of the knee The patient may move around in bed in this as soon as it is dry but should not walk for another month. After a further 2 months of gentle ambulation in the plaster spica the fusion will usually be such as to leave no doubt of its solidity on X-ray examination and external splints may be discarded

Spina Bifida

Failures of fusion of the posterior neural arches are most often found in the lumbo-sacral region and in the sacrum. Indeed, failure of complete fusion in the sacrum is so common as to be hardly abnormal. The spina bifida which is of pathological and therapeutic importance is that which affects the lower lumbar vertebræ

This developmental error is classified into five grades according to the severity of the defect. The first usually does not need any treatment, the second should be treated, the third may be, and the fourth and fifth are too severe to allow of effective treatment. The last two are usually associated with other developmental errors or with neurological complications such as make impossible the establishment of normality

(1) Spina Bifida Occulta. This is the slightest defect, and usually causes no loss of function. It is commonly found incidentally during routine radiography but a tell tale patch of hair over the lumbo-sacral region may suggest its presence. It is seen as a linear defect in the neural arch in the region of the spinous process or processes, usually of the fifth and possibly the fourth lumbar vertebræ. The arch of the sacrum below it is completely bifid The condition can usually be disregarded. Very occasionally symptoms and signs of neurological deficit in the lower limbs may be manifest in adolescence. These are caused by the presence of a *membrana reuniens* which is a firm fibrous band extending between the dura mater in the region of the conus medullaris and the site neighbourhood of the bony defect As the cord rises in the spinal canal due to the more rapid growth of the spine than of the cord, the fibrous band does not stretch, and traction is exerted on the lower end of the cord Division of the band by operation relieves the condition.

(2) Meningocele. A pouch of dura mater projects backwards through the defect in the neural arch and is covered only by a layer of thin transparent skin called the membrana pellucida. The nerve roots lie in their normal position, and as the defect does not extend high enough the spinal cord is not affected There are, therefore, no neural complications, and often no associated congenital defects elsewhere.

The lesion is eminently suited to radical surgical treatment, and this should be undertaken without delay Newly born babies withstand surgical operation well. Furthermore, if operation is delayed the skin overlying the pouch of dura mater will ulcerate and meningitis will ensue. The operation consists of removal of the sac and the abnormal skin repair of the defect in the dura mater approximation of the posterior spinal muscles, and closure of the skin. It is not a difficult procedure and gives a satisfactory result

(3) Myelomeningocele. In this, the neural tissues are involved. The lumbar nerve roots, instead of running in their normal place in the spinal canal, are displaced

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(4) SYRINGOMYELOCELE AND MYELOCELE. These are the last and most severe degrees of this congenital defect. In the first the neural tube is expanded and is contained within the dural sac. There is a complete and irremediable paraplegia There are often gross congenital defects elsewhere The child seldom survives Myelocele is the final degree in which not only is there a defect in the neural arch and a failure of closure of the dura mater but also the neural tube itself is incomplete The condition is beyond hope of treatment and death from meningitis is inevitable and merciful.

ACQUIRED ABNORMALITIES

Spondylolysis and Spondylolisthesis

The basic feature of these conditions is a defect in the pars interarticularis of the neural arch—a *spondylolysis* It has been taught that this condition is due to a failure of endochondral ossification at the site of the lesion. Recent work, however has shown that this failure of ossification does not occur and strong evidence has indicated that the condition is in fact a stress fracture of the neural arch. The most convincing argument is that put forward by Stewart (1953) who showed that the lesion is very common in Alaskan Esquimaux and related it with their habit of spending long hours working in a squatting position. Once the defect in the neural arch has developed, the body of the affected vertebra can be displaced forward on the body of the vertebra below This forward slipping is called *spondylolisthesis* As might be expected the vertebrae most commonly affected are those in which there is the greatest forward inclination, the fifth and the fourth lumbar vertebrae The slip may be only slight—a few millimetres—or it may be so gross that almost the whole depth of the vertebral body is displaced forwards. In the more severe degrees there may be symptoms and signs indicative of irritation of and interference with the function of the lumbar nerve roots. In all degrees there is disruption of the affected intervertebral disc which may amount to complete destruction of both the nucleus pulposus and the annulus fibrosus

The first, and usually dominant symptom, is low back pain increased in severity by exertion and by stooping There is often some limitation of forward flexion of the lumbar spine and some spasm of the lower part of the erector spinae muscles There is tenderness on pressure over the interspinous ligament at the level of the lesion, and on either side of the spine in the region of the facet articulations and there may be sciatic signs and symptoms due to pressure on the lumbar nerve roo[illegible] page 564) The condition is not caused by isolated trauma, but is of gradual [illegible] the patient's attention may be drawn to it by re[illegible] sustaining a su[illegible] to the already weakened back This is a point [illegible] give rise to dif[illegible] cases.

X ray diagnosis of spondylolisthesis does not present any difficulty The displacement is readily seen in a lateral projection of the lumbo-sacral region and a good quality film will also show the degree of damage to the intervertebral disc and the amount of associated osteophytic formation It is not so easy to demonstrate spondylolysis before the slip has occurred, though the symptom of low back pain may be of considerable severity Oblique projections of the affected region are needed. These pass at right angles across the pars interarticularis and show the lesion, either as a linear gap if there is no slip, or as a wide interval between the superior and the inferior articular processes if there is a forward displacement of a vertebral body

A trial should be made of conservative treatment along the lines already discussed namely change of occupation, spinal extension exercises, and the use of a lumbar corset. If these fail to give relief a lumbo-sacral fusion should be performed from the fourth or the third lumbar vertebra to the sacrum. The posterior fusion already described is the operation of choice. Fusion of the bodies from an anterior or antero-lateral approach would seem an attractive alternative, but no easy and reliable method of achieving this has yet been devised. If there is evidence of involvement of the lumbar nerve roots, the spinal canal should be opened and the offending osteophytes should be removed, or the bony step should be trimmed These procedures complicate the operation considerably and should not be undertaken by one who is not accustomed to working within the spinal canal. They call for greater operative skill and judgment than operations on an uncomplicated prolapse of an intervertebral disc (q v) which may cause a similar clinical syndrome.

Osteoarthritis and Senile Osteoporosis

With increasing age the intervertebral discs undergo progressive degeneration. This happens in some degree to everyone The process is accelerated by heavy exertion, as in the occupations of coal-mining, dock labouring, steel-erecting, and the like It is evident that there is also a constitutional factor and that in some individuals the intervertebral discs wear out more rapidly than in others The symptom is pain in the back, made worse by exertion with often a complaint of stiffness on change of posture. The condition affects mainly the more mobile regions of the spine the lumbo-sacral and the lower cervical. The onset of the pain is gradual, but it may be exacerbated by acute strain There may be pain down the arm, girdle pain, or sciatic pain depending upon how and where the osteophytes involve the spinal nerve roots. Radiographs show evidence of degeneration of the intervertebral discs in narrowing of the intervertebral spaces, and there is secondary osteophytic formation which may be gross. There is, however no definite relationship between the amount of osteoarthritic change seen in the radiograph and the severity of the resultant pain Often gross osteoarthritis is seen radiographically in patients who do not complain of back pain. Treatment is essentially conservative. Physiotherapy does not produce lasting relief though it may help in acute exacerbations of the pain. Most benefit is obtained from the wearing of a suitable brace (*see page 527*), carefully moulded to the contours of the spine Occasionally a small localized area of osteoarthritis due to old trauma may be suitable for treatment by local spinal fusion. Such an area is found most commonly at the thoraco-lumbar level. Posterior arthrodesis should be accurately localized to the involved intervertebral joint, and not more than two or at most three vertebræ should be fused The shorter

backwards into the dural sac which they traverse, sometimes adherent to its periphery The defect extends more proximally and the conus medullaris may be involved. *Associated neurological lesions are not uncommon, even to the extent of partial or* complete paraplegia, and there may be interference with the function of the bladder and the bowel. There are frequently other concomitant congenital abnormalities such as club-foot, hare-lip cleft palate, and cardiovascular errors. Even if there are none of these associated abnormalities operation frequently fails to achieve normality and some degree of neurological defect in the lower limbs at least may be permanent. Operative repair is not easy and the prognosis is not good, but the operation should be undertaken.

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ACQUIRED ABNORMALITIES

Spondylolysis and Spondylolisthesis

The basic feature of these conditions is a defect in the pars interarticularis of the neural arch—a *spondylolysis*. It has been taught that this condition is due to a failure of endochondral ossification at the site of the lesion. Recent work, however, has shown that this failure of ossification does not occur and strong evidence has indicated that the condition is in fact a stress fracture of the neural arch. The most convincing argument is that put forward by Stewart (1953) who showed that the lesion is very common in Alaskan Esquimaux and related it with their habit of spending long hours working in a squatting position. Once the defect in the neural arch has developed, the body of the affected vertebra can be displaced forward on the body of the vertebra below. This forward slipping is called *spondylolisthesis*. As might be expected, the vertebræ most commonly affected are those in which there is the greatest forward inclination, the fifth and the fourth lumbar vertebræ. The slip may be only slight—a few millimetres—or it may be so gross that almost the whole depth of the vertebral body is displaced forwards. In the more severe degrees there may be symptoms and signs indicative of irritation of and interference with the function of the lumbar nerve roots. In all degrees there is disruption of the affected intervertebral disc which may amount to complete destruction of both the nucleus pulposus and the annulus fibrosus.

The first, and usually dominant symptom, is low back pain increased in severity by exertion and by stooping. There is often some limitation of forward flexion of the lumbar spine and some spasm of the lower part of the erector spinæ muscles. There is tenderness on pressure over the interspinous ligament at the level of the lesion, and on either side of the spine in the region of the facet articulations and there may be sciatic signs and symptoms due to pressure on the lumbar nerve roots (see page 564). The condition is not caused by isolated trauma but is of gradual onset, though the patient's attention may be drawn to it by reason of sustaining a sudden strain to the already weakened back. This is a point which may give rise to difficulty in medico-legal cases.

X ray diagnosis of spondylolisthesis does not present any difficulty The displacement is readily seen in a lateral projection of the lumbo-sacral region, and a good quality film will also show the degree of damage to the intervertebral disc and the amount of associated osteophytic formation It is not so easy to demonstrate spondylolysis before the slip has occurred, though the symptom of low back pain may be of considerable severity Oblique projections of the affected region are needed These pass at right angles across the pars interarticularis and show the lesion, either as a linear gap if there is no slip, or as a wide interval between the superior and the inferior articular processes if there is a forward displacement of a vertebral body

A trial should be made of conservative treatment along the lines already discussed, namely change of occupation, spinal extension exercises, and the use of a lumbar corset. If these fail to give relief a lumbo-sacral fusion should be performed from the fourth or the third lumbar vertebra to the sacrum. The posterior fusion already described is the operation of choice. Fusion of the bodies from an anterior or antero-lateral approach would seem an attractive alternative, but no easy and reliable method of achieving this has yet been devised. If there is evidence of involvement of the lumbar nerve roots, the spinal canal should be opened and the offending osteophytes should be removed, or the bony step should be trimmed These procedures complicate the operation considerably and should not be undertaken by one who is not accustomed to working within the spinal canal They call for greater operative skill and judgment than operations on an uncomplicated prolapse of an intervertebral disc (q v) which may cause a similar clinical syndrome.

Osteoarthritis and Senile Osteoporosis

With increasing age the intervertebral discs undergo progressive degeneration. This happens in some degree to everyone. The process is accelerated by heavy exertion, as in the occupations of coal-mining, dock labouring, steel-erecting, and the like. It is evident that there is also a constitutional factor and that in some individuals the intervertebral discs wear out more rapidly than in others. The *symptom is pain in the back*, made worse by exertion, with often a complaint of stiffness on change of posture. The condition affects mainly the more mobile regions of the spine, the lumbo-sacral and the lower cervical. The onset of the pain is gradual but it may be exacerbated by acute strain There may be pain down the arm, girdle pain, or sciatic pain depending upon how and where the osteophytes involve the spinal nerve roots. Radiographs show evidence of degeneration of the intervertebral discs in narrowing of the intervertebral spaces, and there is secondary osteophytic formation which may be gross. There is however no definite relationship between the amount of osteoarthritic change seen in the radiograph and the severity of the resultant pain Often gross osteoarthritis is seen radiographically in patients who do not complain of back pain. *Treatment* is essentially conservative. Physiotherapy does not produce lasting relief though it may help in acute exacerbations of the pain. Most benefit is obtained from the wearing of a suitable brace (*see page 527*), carefully moulded to the contours of the spine. Occasionally a small localized area of osteoarthritis due to old trauma may be suitable for treatment by local spinal fusion. Such an area is found most commonly at the thoraco-lumbar level. Posterior arthrodesis should be accurately localized to the involved intervertebral joint, and not more than two or at most three vertebræ should be fused The shorter

the segment of spine which is immobilized the less are the normal mechanics of the spine deranged and the more dependable is the fusion. The vertebræ to be dealt with are determined radiologically with suitable markers applied before or during the operation. It should be remembered that in antero-posterior X rays of the lumbo-sacral region the shadows of the tips of the spinous processes overlie the bodies of the vertebræ immediately below those from which they project. Thus the tip of the twelfth dorsal spinous process lies behind the body of the first lumbar vertebra The operation is similar to that for lumbo-sacral fusion, but a plaster bed is not needed A plaster shell until the sutures are removed, and then a plaster jacket, provide adequate immobilization

When with increasing age appositional ossification begins to fail, the vertebral bodies become progressively osteoporotic (senile spondylitis) The nuclei of the intervertebral discs bulge into the centres of the bodies, and the bodies themselves may undergo spontaneous fracture The pain associated with these age changes is often persistent and severe A properly fitting Thomas back support affords considerable, and sometimes dramatic, relief Frequent rest periods in recumbency are helpful, together with remedial exercises to improve muscular competence Hormone therapy has been advised.

Vertebral Epiphysitis

The secondary ossific centres of the vertebral bodies are ring-shaped epiphyses sited one on the upper margin and one on the lower margin of the body They are responsible for some of the growth in depth of the vertebræ They begin to ossify at about ten years and they finally fuse at about twenty years. Like all growing epiphyses which are subjected to strain, they are affected by juvenile osteochondritis. The part of the epiphysis which is most affected is that which is exposed to the greatest stress, namely the anterior margin The growth in depth of the anterior parts of the vertebral bodies is thus impaired, and there is exaggeration of the normal kyphosis of the dorsal spine which is the area particularly affected—hence the descriptive name of *adolescent round back* which is sometimes given to the condition.

Attention may be directed to the back either because of the subjective symptoms of aching pain during adolescence or a parent or school teacher may notice that the child is becoming progressively kyphotic or "round-shouldered"

The diagnosis is not difficult. Pain is usually worse after exertion and in the evening resting pain is not common There are no symptoms of general ill health Examination shows a smooth rounded exaggeration of the normal dorsal kyphosis, quite different in appearance from the angular deformity which results from tuberculous osteitis of the dorsal spine. There is no point of acute local tenderness, and there is no spasm of the erector spinæ muscles on forward flexion which is easy and unrestricted. A lateral radiograph shows exaggeration of the dorsal curve due to anterior wedging of several dorsal vertebræ This is usually maximal in the region of the seventh, eighth, and ninth dorsal vertebræ but the abnormality may extend both higher and lower The epiphyses are irregular and fragmented, or may show complete failure of ossification The important differential diagnosis is between epiphysitis and tuberculous osteitis. The two points of difference are that tuberculosis shows an area of bone destruction, an osteolytic lesion and that tuberculosis more commonly shows a maximal change both clinically and radiologically in one or two adjacent vertebræ whereas epiphysitis affects several vertebræ

The treatment, as in that of all juvenile osteochondritis, is to protect the growing epiphysis against strain until the epiphysis is fused and to prevent deformity Postural and spinal extension exercises may be enough A spinal brace may be needed Sometimes a plaster jacket is required and occasionally it may be necessary to advise a period in a plaster bed

Spondylitis Ankylopoietica

This mysterious condition is a non-specific infective process which affects young adults, males much more commonly than females It is manifest in three forms. The first affects only the sacro-iliac joints In the second the disease spreads from the sacro-iliac joints and affects all the elements of the intervertebral and costo-vertebral joints the symphysis pubis, the xiphisternal synchondrosis and the hip joints also show changes. In the third and most serious form, all the joints of the body may be affected, and the end result may be one of truly tragic crippling.

The pathology of the condition is obscure There is a non-specific inflammation of the ligaments surrounding the affected joints and of the cartilage of the synchondroses. There is no change in the bone itself except in the sacro-iliac joints where the adjacent margins of the sacrum and ilium become sclerosed The infective nature of the lesion is suggested by the raising of the erythrocyte sedimentation rate Later the inflamed ligaments ossify progressively and in the synchondroses the cartilage also ossifies and fuses so that the joint becomes completely obliterated. This ossification begins in the sacro-iliac joints and gradually extends up the spine and, in the most severe forms of all, to the joints outside the spine. As the ossification progresses, the pain diminishes, but the disability due to lack of movement is permanent.

The earliest complaint is one of aching pain in the low back, and sometimes of a painful stiffness of the back. The patient may feel generally not in robust health, and be inclined to tire easily The spine, even in the early stages, is straighter than normal through flattening of the normal lumbar lordosis. Quite early there may be a tendency to a forward stoop—a generalized C-shaped kyphosis. There is tenderness on pressure over both sacro-iliac joints and over the spinous processes of the whole lumbar and lower dorsal areas. The most characteristic clinical feature is the marked limitation of all movements of the spine. The first to be affected is extension—when the patient is asked to arch his back, he fails to do so and merely leans back upon the hip joints. There is no lateral flexion or rotation The poker like rigidity of the spine is quite typical and once it has been seen is unmistakable. It may be recognized even through ordinary clothing. The onset of this stiffness precedes that of the abnormal ossification, and may be well-marked when there are no abnormal radiological appearances, save only in the sacro-iliac joints. The erythrocyte sedimentation rate is always raised, the level varying from 15 mm. in 1 hour to 40–50 mm. in 1 hour depending on the severity and extent of the process. The patient is almost always spare in build and does not look or feel well.

The earliest X-ray changes are seen in the sacro-iliac joints. They lose their definition and begin to look blurred and somewhat vacuolated, with some sclerosis in the ala of the sacrum and in the adjacent ilium. These joints are ultimately entirely obliterated. Ossification is next seen in the ligaments of the spinal joints, the anterior and posterior common ligaments, the annulus fibrosus, and the capsules of the facet articulations.

The appearance in the spine when the condition is fully established has been likened to that of bamboo or of poured lead—the intervertebral joints show as bulging bony prominences exactly similar in appearance to the wiped joint which the plumber makes in lead piping. The X-ray changes in the joints outside of the spine follow a similar pattern of capsular ossification followed by obliteration.

Treatment consists of measures to arrest the process, and measures to prevent deformity of the spine from adding to the disability of limitation of movement. It is fortunate that deep X ray therapy is effective in arresting the condition The therapy formerly was given by the wide field technique in which, when the spine was irradiated, so also was most of the trunk, and undesirable secondary radiation effects were not uncommon. By the development of the so-called *glancing field* technique, the radiation can be much more accurately localized to the affected joints, and a much larger dose can be given without danger of side-effects. It must be remembered, however that in women it is not possible to irradiate the sacro-iliac joints without also exposing the ovaries, and the possible effects of this must be borne in mind in planning treatment In the favourable case seen early one course of irradiation may be enough to abort the disease, and even when it has progressed to ossification in the lower spinal ligaments, it may be wholly arrested before movement in the rest of the spine is irreparably lost.

If untreated, the spine becomes progressively more stiff and bent forward until the patient's back ultimately becomes immobile in a C-shaped forward curve Such a patient is in a truly pitiable condition When he stands he cannot raise his head to bring his eyes to the horizontal and he can see only his toes or the ground immediately in front of him. This lamentable state of affairs must be avoided Every effort must be made to keep the spine straight so that, even if treatment fails to arrest the ankylosis at least the patient can stand with his eyes level and can look straight before him For this reason it is best for the patient with the more severe involvement of the spine to wear some form of spinal support and to sleep in a plaster bed until the acute phase is arrested If the patient comes late with an established C-shaped kyphosis the back may be straightened by osteotomy of the spine at the dorso-lumbar level after the method described by Smith-Petersen This is a severe and hazardous operation, but when it succeeds the patient is most pathetically grateful for the widening of his horizon This degree of deformity should, however never occur if the condition is properly managed from the first. *This is a dire and severely disabling disease when it is not treated, but* treatment can do much to mitigate its effects. Its early recognition is, therefore, of prime importance.

Coccydynia

Pain in the sacro-coccygeal joint is a distressing symptom and one which has a reputation for having a basis which is largely functional. The symptom complained of is pain at the bottom of the spine—"right in the tail" There is sometimes a history of trauma such as a fall on to or a blow over the coccyx, or the onset may follow childbirth in which, of course it is quite conceivable that the sacro-coccygeal joint might be injured. In such patients the question of a functional element need not arise but not infrequently the onset is insidious and not clearly related to any trauma. The pain is of an intense boring character and is made worse by sitting it may however also be felt in bed and interfere with sleep There is frequently no definite abnormality to be

detected. The coccyx is tender and there is pain when it is moved between the finger in the rectum and the thumb in the natal cleft, but this manipulation is uncomfortable even when there is no sacro-coccygeal abnormality The surgeon must satisfy himself that there is no disease of the lumbar spine or pelvic viscera which may cause pain referred to the coccyx. Radiography may or may not show arthritic changes in the sacro-coccygeal joint.

The diagnosis is an anxious one, and an opinion should be formed only after close consideration of the history If the basis is functional local treatment will be ineffective or may be harmful if not to the patient at any rate to the surgeon s peace of mind If there is any doubt, the correct line is to reassure the patient that the condition, although it is undoubtedly a nuisance, is essentially benign and that it may subside naturally If active measures are decided upon, the correct treatment is excision of the coccyx. Palliative measures such as manipulation of the sacro-coccygeal joint under anæsthesia and physiotherapy are of doubtful value the injection of long-lasting local anæsthetic or sclerosing agents is better avoided

LESIONS OF INTERVERTEBRAL DISCS

Although the occurrence of pathological changes in the intervertebral discs had been previously described, it was only after the paper by Mixter and Barr (1933) that it was recognized that herein lay the cause of many symptoms whose origin had previously been obscure. Many of the ideas about the causation of backache and sciatica were without any sound pathological basis, and much of the treatment was purely empirical. Since 1933 much thought has been directed to these conditions, many problems have been solved through an understanding of their underlying pathology and a vast literature has accumulated. The exact nature of the pathological or physico-chemical changes have not yet been elucidated, but enough is known about their nature and of their effects both on the spine and on the nerve roots to make possible an approach to the problems founded at least on an understanding of their mechanics

The intervertebral discs are the elastic cushions which are interposed between the vertebral bodies. They consist of a ring of dense fibrocartilage which is intimately connected with the margins of the vertebral bodies, the *annulus fibrosus* and a central core of amorphous material, the *nucleus pulposus*, which is the remains of the notochord.

The function of the intervertebral discs is to join together the vertebral bodies, to act as shock absorbers, and to allow of movement in the spinal column The amount of movement in any one intervertebral joint is small but the summation of the movements at the several joints allows of a considerable range in the spine as a whole One has but to think of what an acrobatic dancer can do with her spine to realize this.

It has already been seen that the intervertebral discs undergo generalized degenerative changes in common with other collagenous structures. We are more concerned with local manifestations of these changes. They occur in the regions of the spine where the stress on the intervertebral joints is greatest, namely in the lower part of the lumbar spine and towards the lower end of the cervical segment It is, therefore clear that there is a mechanical factor in the ætiology There is also however an underlying physico-chemical change in the discs themselves which results in swelling of the nucleus pulposus and consequent degeneration, protrusion and ultimately rupture of the annulus fibrosus.

gross narrowing and secondary osteoarthritis the condition is quiet, and the cause of the trouble may be found to be protrusion of the disc between the fourth and fifth lumbar vertebræ.

Treatment. Because the condition is essentially benign treatment should at first almost invariably be conservative. The only exception to this is in the rare instance when the sciatic pain of the first attack is so severe that it cannot be controlled by sedation, and operation must be undertaken without delay In general it may be said that operation should be reserved for those patients who show evidence of lumbar nerve root involvement those in whom the symptoms and signs are predominantly in the back are not favourable subjects for operation and do better under conservative measures The aim of treatment is to counteract the irritation of the lumbar nerve roots. When the disc swelling is merely a protrusion of the nucleus pulposus under an intact annulus the swelling will subside if the back is put at rest, and the pain will abate. Some of the nucleus pulposus may be displaced from between the vertebral bodies and lie under the bulging but still intact annulus. In these patients conservative treatment still may succeed, as the displaced portion either shrinks or returns to its position When the annulus is torn and the displaced fragment of nucleus pulposus is actually sequestrated into the spinal canal, the chances of success with conservative treatment are slender but are still not hopeless. It is of the greatest importance however that conservative treatment should not be persisted in for more than about 6 weeks if the sciatic symptoms do not show signs of subsiding. The irritated and mechanically inflamed nerve root is contained within a cuff of dura mater and if adhesions are allowed to develop in or around this cuff the resultant chronic pain may defy all efforts at treatment, either conservative or operative

The conservative treatment consists essentially of resting the affected portion of the back until the œdema of the nerve root, traumatic or otherwise subsides. The patient should be put to bed at once The longer he tries to remain active in spite of the pain the more firmly does the œdema become established and the longer it takes to settle. The bed should be firm—an ordinary hair mattress laid on boards is best. Not more than one pillow is allowed at first two may be permitted as the pain subsides. The patient should lie on his back and not move on to his side or his face. Sedation should be used as necessary Aspirin and codeine are normally adequate but in the early stages pethidine or even morphine may be needed If the patient finds it difficult to sleep in the supine position, suitable barbiturates are given at night Some patients are greatly helped by the use of pelvic traction, applied through a canvas belt upon an inclined bed higher at the foot.

Under this régime the pain should subside within a few days and should be almost gone in about two weeks. Then back raising exercises may be begun There are many varieties of these, but the two most important are (1) the patient lies on his face and simultaneously raises his chest and shoulders and his lower limbs from the bed (2) the patient lies on his back and puts his spine into hyperextension lifting his buttocks from the bed and having only his heels and his shoulders on the bed These are both severe exercises and some less strenuous variant may be used to begin with, but it is important that the posterior spinal muscles be developed until these two exercises can be performed without undue difficulty At about 3 weeks the patient may begin to get up A firm lumbar corset is of value at this stage, an appliance similar to that recommended for

lumbo-sacral pain of other origin This should be worn until the patient has been free from pain for 3 months, and may then be progressively discarded. The patient must be warned against ever subjecting his back to stooping and lifting strains, and should continue with spinal extension exercises indefinitely The possibility of recurrence of the prolapse must always be borne in mind

In the less severe degrees of pain it may be possible to keep the patient ambulant during treatment by resting the back in a plaster jacket, extending from the pelvis upwards over the lower ribs It is applied with the patient standing, or preferably while he is suspended by a head halter so that most of his weight is off his feet If the jacket relieves the pain it is replaced by a canvas corset in three or four weeks, spinal extension exercises being carried out as before. If the plaster does not relieve the pain, then a period of bed rest is tried.

Operative Treatment. If in spite of these measures, the pain persists and particularly if there is any marked root symptom or sign operation should be undertaken. Sciatic pain should not be allowed to persist for more than 4 weeks, or 6 at the outside lest intractable root adhesions form. The operation consists of exposure of the affected disc, incision of the annulus fibrosus at the site of the protrusion and removal of all of the nucleus pulposus, not merely the protruded portion The operation is best performed with the patient prone lying in such a way that the abdomen is free so that the abdominal venous return is not impeded, thus preventing troublesome bleeding from the extradural venous plexus. For this reason some surgeons prefer to operate with the patient on his side or in the knee-elbow position This is a matter of personal choice. The muscles are cleared from the back of the neural arches. The sacrum and the fifth neural arch are dependable landmarks The sacrum is easily recognized, and the fifth neural arch has a well-defined ridge on it which no other neural arch has. The ligamentum flavum over the suspected site of the prolapse is excised, and enough bone is nibbled away from the adjacent neural arches to allow of access to the spinal canal This is better than complete or hemi laminectomy Although it is not quite so easy the method has the advantage that it causes less interference with the stability of the spine, and if spinal fusion should be needed later it is more readily secured than if the whole or a half of the lamina had been removed. The dura is seen as a bluish translucent membrane. It is gently moved towards the midline and the nerve root is seen This too is mobilized inwards, and the prolapse should be in view If there is not a prolapse at the site suspected then the space above or below should be explored. When the clinical picture is as described there is a prolapse if none is found then there is some other lesion such as a cauda equina tumour or the like

When the prolapse is found the annulus is incised and all the nucleus is removed with a rongeur forceps. This stage of the operation is time-consuming, but the removal must be thorough otherwise there will be a recurrence When a portion of nucleus is actually sequestrated it must be realized that it may have migrated from its source. Thus, if a portion of free nucleus be found in the neighbourhood of the lumbo-sacral disc in contact with the first sacral root it may have been extruded from the space above. If the lumbo-sacral annulus appears normal, the disc above should certainly be explored. Spinal fusion is not indicated in a primary disc operation, although exploration of a disc or discs may be a part of the treatment when fusion has been previously decided upon. The patient should be allowed to get up within a few days and the long-term

after-care and advice are the same as in those who are treated conservatively—spinal extension exercises and avoidance of stooping strains.

The treatment of the long standing disc lesion with root adhesions presents a much more difficult problem Simple removal of the disc is not enough—indeed, the prolapse is very often found to be shrivelled and insignificant. Freeing of the root is difficult, and it is well nigh impossible to prevent the adhesions from reforming. Probably the best way to treat such a patient is by lumbo-sacral fusion, but the prognosis must be guarded. Before this is done the patient's lumbo-sacral region should be immobilized for a trial period of 4 weeks in a short plaster spica. If this immobilization relieves the pain operation is worth while If it does not, all that can be advised is palliation and sedation. It may be said that motor weakness is almost always permanent so also is loss of the deep tendon reflexes, but this, fortunately does not matter

Cervical Disc Lesions

The other common site for disc protrusions is the lower part of the cervical spine, in the region of the fifth, sixth, and seventh cervical vertebræ. Once more it will be noted that this is an area in which the vertebral bodies are normally subjected to antero-posterior shearing force The effects of the disc lesion are, as in the lumbar region, two-fold—those produced in the intervertebral joint and those due to involvement of the nerve roots. There is cramping pain and stiffness in the neck and there is reference of neurological signs, pain, paræsthesia, and muscle weakness or inco-ordination in the upper limbs. Very occasionally a prolapse is large enough to cause pressure on the spinal cord which at this level occupies most of the spinal canal This calls for urgent relief by operation, but otherwise it is seldom necessary to operate on cervical disc lesions. They have a natural tendency to spontaneous subsidence, and they are also much more susceptible than lumbar lesions to conservative treatment. In the rare instances in which it fails, operation is indicated. The operation is not easy because the cord and the nerve roots occupy most of the space within the spinal canal, and operation in close proximity to so much important nervous tissue should be done by one who is trained in handling such tissue—a neurosurgeon.

The two conservative measures are immobilization of the cervical spine and longitudinal neck extension. In the more severe cases these may be combined the patient being treated in bed with a head halter and pulley and weights or by skull traction with calipers. This is almost always rapidly effective save when the cord is involved but in that case operation is an urgent necessity In the milder cases intermittent neck extension by means of a head halter and some form of pulley traction is used twice a day and in the intervals the neck is supported in a collar The most comfortable is some form of light moulded leather or plastic support extending from the mastoid processes to the clavicles.

CHAPTER XVII

PAIN IN THE NECK AND ARM

H. OSMOND-CLARKE

LESIONS of the cervical intervertebral discs (Fig. 310) are probably the most common cause of recurrent attacks of pain in the neck and the arm. Two quite distinct types of disc lesions should be recognized—acute and chronic (Fig. 311)—each with its own pathological, clinical and X-ray picture, and for each of which operation when indicated must follow a different pattern and is associated with quite different risks.

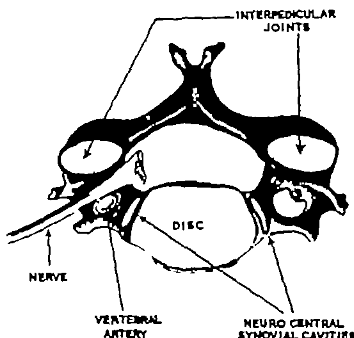


FIG. 310. Normal anatomy of a middle cervical vertebra (after Dr. J. W. D. Bull)

ACUTE CERVICAL DISC LESIONS

Acute prolapse of a cervical disc is largely an affliction of the young and it is at least ten times rarer than similar lesions in the lumbar region. It is often an immediate result of flexion injuries as, for example, when an individual dives into unexpectedly shallow water and there is some evidence to support the view that the sudden extension followed by flexion movements which are produced when a stationary car is run into from behind —what is called in America the "whip-lash" injury which causes such intransigent neck-ache and arm-ache and which is now almost the largest medico-legal problem following automobile accidents in America—cause damage to the intervertebral disc mechanism of the cervical spine.

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H Osmond-Clarke

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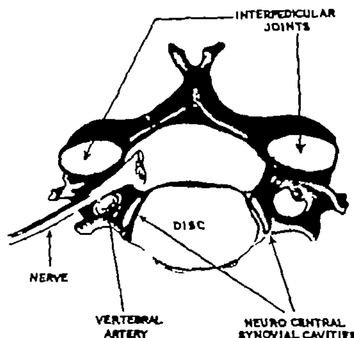


Fig. 310. Normal anatomy of a middle cervical vertebra (after Dr J W D Bull)

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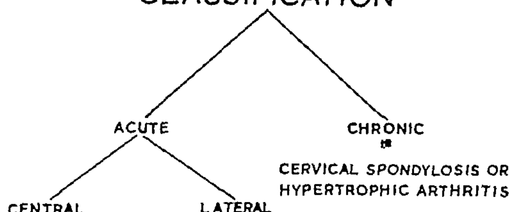


FIG. 311 Classification of cervical disc lesions.

Pathological Anatomy

There are two types of prolapse of the cervical intervertebral disc (Fig. 312)

(*a*) Lateral, which involve the nearby issuing nerve root and sometimes partly the root and partly the spinal cord as well. The usual level is between C5 and 6 or C6 and 7 involving the 6th and 7th roots respectively

(*b*) Central, which are rarer but are often dangerous and require urgent surgical

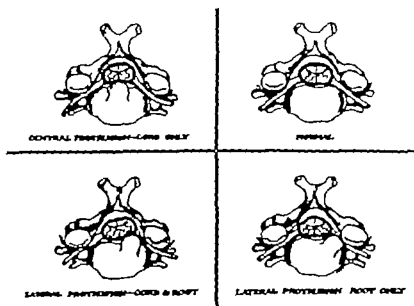


FIG. 312 Diagrammatic representation of the main types of acute cervical disc protrusion (after Dr J W D Bull)

removal The danger arises because of the anatomical circumstances the cervical enlargement of the cord occupying most of the spinal canal and firmly tethered by the dentate ligaments and the nerve roots (Fig 313)—a very different state of affairs from the lumbo-sacral area with its wide canal occupied only by the roots of the cauda equina.



FIG. 313 Showing how the cord occupies most of the spinal canal and how it is tethered by the dentate ligament (*X*) and by the posterior root (*Y*).

Clinical Picture

(*a*) Lateral protrusions if they only cause a derangement of the cervical spine, produce an acute and painful torticollis, with considerable muscle spasm and tenderness particularly in the trapezii when a root is involved there is in addition acute pain exacerbated by coughing or straining in the root distribution with *sometimes* motor sensory and reflex changes. The picture is in fact analogous with the "Lumbago-sciatica" syndrome following acute prolapse of a lower lumbar intervertebral disc.

(*b*) Central. These produce varying degrees of cord compression from an incomplete Brown-Sequard syndrome to gross pyramidal tract involvment with quadriparesis. Sensory fibres are not apparently so vulnerable, though there is usually some bilateral impairment of sensation over a few dermatomes at the level of the lesion and just below Examination of the cerebro-spinal commonly reveals some abnormality raised proteins or a positive Queckenstedt's test, or both.

X-ray Examination

By contrast with chronic disc lesions (cervical spondylosis) radiographs may show little abnormality apart from a straightening of the column instead of the normal cervical lordosis (Fig 314). It is debatable whether this is due to mechanical derangement by the displaced disc or whether it is merely the result of muscle spasm. Myelography shows, in lateral herniations, a failure of filling of the sleeve of dura mater which is



Fig 314 Lateral radiograph showing reversal of the normal cervical lordosis in an acute disc prolapse.

normally prolonged outward along the nerve roots In central lesions a gross filling defect is present (Fig. 315) There is, however no indication for myelography unless operation is imperative as in a central lesion or in the rare lateral lesions which do not respond to conservative treatment.

Differential Diagnosis. The history and clinical picture usually leave little room for doubt. Inflammatory and neoplastic lesions can produce neck and arm pain and all shades of neurological patterns. They are, however more gradual in onset, and produce positive X ray signs. Acute torticollis may occur from irritation of inflamed cervical glands. It can also be due to spontaneous dislocation of the atlas. This is an infrequent complication of infections in the upper part of the neck which are thought to cause hyperæmia of the atlas and consequent loosening of the attachments of the transverse

ligament Radiographs show forward and rotatory displacement of the atlas. Acquired torticollis due to cervical adenitis or spontaneous dislocation of the atlas occurs nearly always under the age of twelve which alone serves to distinguish it from acute disc lesions

Treatment. Lateral protrusions respond to conservative treatment in the large majority of patients. A period of 10–14 days of rest in bed with halter traction (Fig 316) followed by 6 weeks in a plaster of Paris (Fig. 317) or plastic collar is often successful



(a) (b)

FIG. 315 Myelograms of acute cervical disc lesions
(a) Massive prolapse of central type
(b) Lateral prolapse obliterating dural extension along nerve root at arrow
Reproduced by permission of Mr Valentine Logue F R C S

Occasionally the arm pain is not relieved by halter traction, or the patient s skin will not tolerate it skull traction (Fig. 318) is then justifiable as preliminary to the application of a collar

Manipulation other than longitudinal traction, under anaesthesia is never indicated because of the danger of increasing the protrusion.

Operation is always necessary when there is serious cord involvement for lateral protrusions, with root symptoms only operation should be reserved for patients who are not relieved by conservative measures. The removal of an acutely prolapsed soft disc by hemilaminectomy or laminectomy and foraminotomy carries much less risk of damage to the blood supply of the cord than do similar operations designed to remove the hard fibro-cartilaginous bony bar encountered in cervical spondylosis None the less these operations both in acute and chronic lesions are best done by neuro-surgeons with the collaboration of orthopaedic surgeons.

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(a) Massive prolapse of central type.
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Reproduced by permission of Mr. Valentine Logue, F.R.C.S.

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Manipulation, other than longitudinal traction, under anæsthesia is never indicated because of the danger of increasing the protrusion.

Operation is always necessary when there is serious cord involvement. For lateral protrusions, with root symptoms only, operation should be reserved for patients who are not relieved by conservative measures. The removal of an acutely prolapsed soft disc by hemilaminectomy or laminectomy and foraminotomy carries much less risk of damage to the blood supply of the cord than do similar operations designed to remove the hard fibro-cartilaginous bony bar encountered in cervical spondylosis. None the less these operations both in acute and chronic lesions are best done by neuro-surgeons with the collaboration of orthopædic surgeons.

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(a)



(b)

FIG. 316. (a) A simple readily-made halter of felt to provide head traction of about 5 pounds for 7–10 days.

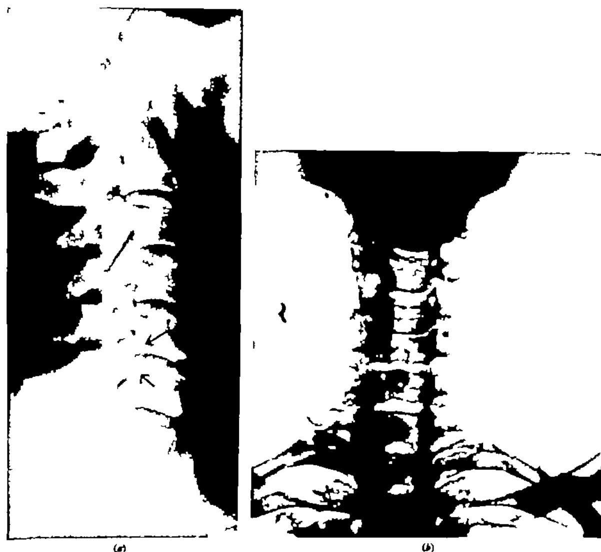
(b) A Sayre halter with elevation of the head-end of the bed to allow body weight to produce more traction.



FIG. 317 A plaster of Paris doll's collar. It is well moulded under the chin, at the angles of the mandible and around the mastoid processes. The hair is suitably trimmed before application.



FIG. 318 Skull traction using Blackburn apparatus.



(*a*) (*b*)

FIG 326 Radiographs of typical cervical spondylosis

(*a*) Lateral view showing narrowing of disc space between C5 and 6 with anterior and posterior marginal lipping

(*b*) Antero-posterior view showing lipping of the neuro-central joints particularly between C5 and 6.

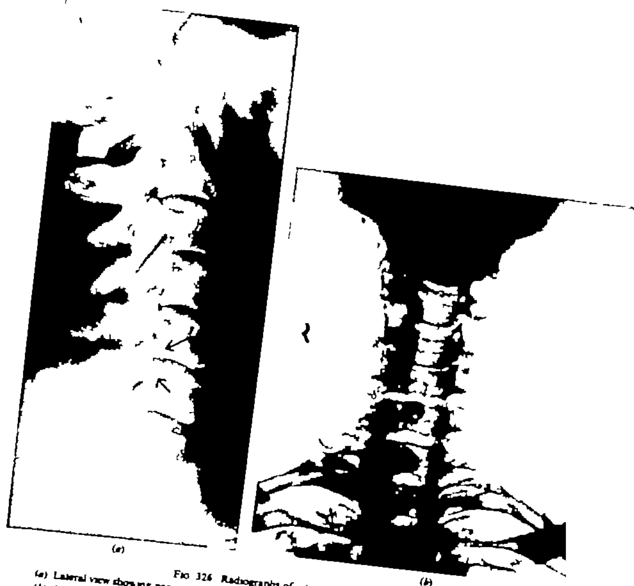
from these joints on the exit foramina is clearly seen in oblique views (Fig. 327) The latter should always be part of a comprehensive X-ray survey of the cervical spine.

Treatment. *Conservative* About two-thirds of all patients with slight and moderate degrees of cervical spondylosis gain relief from intermittent longitudinal stretching with



FIG. 327 Radiograph showing value of oblique view in demonstrating encroachment of osteophytes on the exit foramen between C6 and 7

massage and any of the usual forms of counter irritation. *Shortwave diathermy* and heat help some patients, but in a considerable number heat *in any form* seems to exacerbate the pain, perhaps by increasing congestion around nerve roots. A manipulation with or without anæsthesia can be a help at this stage, though only longitudinal traction is permissible if the patient is anæsthetized forcible rotation, lateral bending, flexion or extension carry risk of root or cord damage, and manipulation under anæsthesia should



(a) (b)

FIG. 326. Radiographs of typical cervical spondylosis.
(a) Lateral view showing narrowing of disc space between C5 and 6 with anterior and posterior marginal lipping.
(b) Antero-posterior view showing lipping of the neuro-central joints particularly between C5 and 6.

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never be used when X-ray changes are gross and when the neck is very stiff. Injections of local anæsthesia and Hydrocortisone into tender areas sometimes give relief. Intermittent traction can be given in many ways. It does not require admission to hospital and intelligent people can be easily taught to apply it at home. The simplest form is to



FIG. 328. Intermittent cervical traction. A Sayre halter attached via an overhead pulley to the chair on which the patient sits. Traction is afforded by the patient's body weight if the cord is tied to the chair while the buttocks are within a few inches of the seat. Traction is finally effected when the patient sits down fully.
Alternatively a weight of 3–5 lb. can be attached to the cord.

wear a felt or a Sayre head sling with traction of about 3–5 lb. over an overhead pulley for 15 minutes twice a day (Fig. 328). If the sitting position is used the time can be spent in reading, knitting, and the like. For writing, reading, and the comparatively new "occupation" of viewing television, seats, desks and sets should all be adjusted so that the neck is in the neutral position. At night pillows should be arranged to prevent kinking. The bed should be firm and not more than two shallow pillows allowed. A useful device is to tie a piece of tape around the top pillow giving it a "bow-tie"

appearance (Fig. 329). The "isthmus" fits into the neck and the wings prevent kinking. Many of these precautions should be used indefinitely though when symptoms are relieved traction and physiotherapy can be stopped. For those who do not respond to these measures a collar is helpful but it is of course a social embarrassment to many people. If symptoms are very acute a three week period of continuous traction in bed is a useful prelude to the fitting of a collar—at first a simple felt affair reinforced by plaster of Paris is the cheapest and often the most comfortable arrangement. If prolonged wear

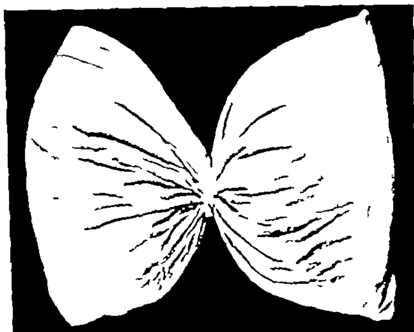


Fig. 329 Illustrating a satisfactory way of preventing kinking of the neck during sleep. Two thin pillows only are allowed, the uppermost being tied in two with tape. The waist of the "bow-tie" thus formed is placed under the neck, and the wings support the head.

is necessary there are several types—leather, plastic (Fig. 330), and light metal frames (Fig. 331)—available. Though a collar does not at first commend itself to most women it is often dramatic how quickly pain is relieved. Thus many housewives prefer to use a collar almost indefinitely for household chores, for knitting and reading, for gardening and for travel.

A combination of these conservative measures produces relief in about 95 per cent of all sufferers seen in orthopaedic practice. It is tempting to speculate that traction and manipulation help when the roots are tethered by adhesions, and that a collar is effective when the roots are being subjected to friction and when there is a flare of arthritis in the adjoining intervertebral joints producing swelling and oedema.

Operative. Operation is indicated in two circumstances:

(*a*) When a collar gives complete or substantial relief followed repeatedly by relapse when it is removed, fusion of the two affected vertebrae with one above and one below

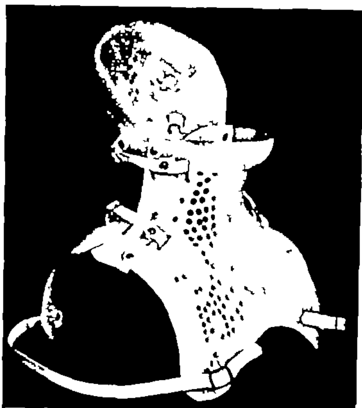


FIG. 330. A light plastic collar

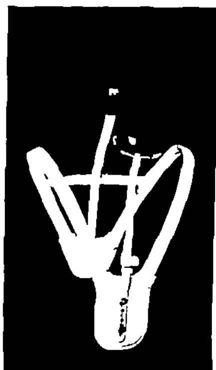


FIG. 331. The Strudwick cervical support. A light metal framework which can be slipped on quickly over the head and provides support for the chin in a plastic cup while the occiput is firmly held to prevent rotation.

(Photograph by courtesy of Ellis Strudwick & Co. Ltd. London).

i.e. four vertebræ in all is justified (Fig. 332). In this small group it is unnecessary to explore the cord or nerve roots. Fusion is performed by "rawing" the spinous processes and the laminæ, and inserting tibial or iliac bone grafts.

(*b*) When root or cord signs are gradually progressive or severe. This small group of less than 2 per cent of all patients with cervical spondylosis requires the most careful and judicious neurological, neuro-surgical and orthopædic assessment. A myelogram



FIG. 332. Cervical spondylosis C4–5. Relieved by collar but relapsing always on removal of collar. Permanent fixation by grafting of C3, 4, 5, 6, so that collar could be discarded. Laminectomy not necessary.

should always be done in this small group of patients (Fig. 333). The correct operation is decompression of the cord and roots by laminectomy and "unroofing" of the exit foramina (Fig. 334). Attempts to remove the bony-cartilaginous bars in front of the cord or the roots are unwise: they are likely to increase local neural damage either at the time of operation or later by thrombosis of the vessels supplying the cord and roots. Division of the dentate ligament (and the posterior root, though this is not so often necessary) (Fig. 335) helps to free the cord so that it and the affected nerve roots can "float" backwards from intimate contact with the osteophytes on the vertebral body and the foramina. This decompression is a delicate and time-consuming procedure. When the decompression is completed the area of laminectomy should be stabilized by whatever bone-grafting method seems desirable: an anterior fusion of the affected bodies through an antero-lateral approach some weeks after decompression is often easier and more effective than grafting the gap posteriorly (Figs. 336 and 337).

The writer after a considerable experience would like to re-emphasize that the decision for or against operation should be decided only after most careful consideration by neurologist, neuro-surgeon, and orthopædist, and that the operation should be a combined neuro-surgical and orthopædic venture.

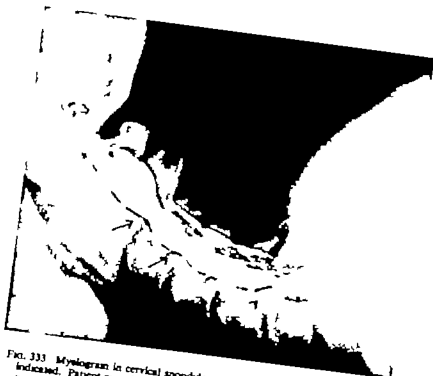


Fig. 333 Myelogram in cervical spondylosis. Performed only when operation is indicated. Patient must lie on face so that the opaque medium pools on the posterior surface of the vertebral bodies. Though there are slight protrusions at C2 and 3 and C3 and 4 the important one was the large one between C5 and 6.

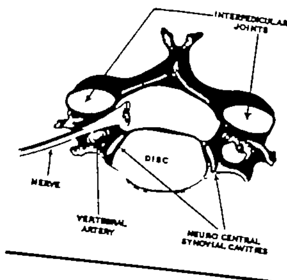
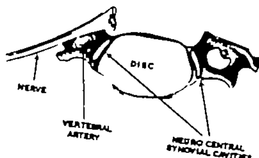


Fig. 334 Diagram showing *above* the normal anatomy. *Below* the amount of bone and joint excision necessary to decompress the cord and the roots. It means the removal of spinous processes, laminae, and posterior wall of the root foramina. To decompress a root on one side, obviously does not require such extensive removal of bone.



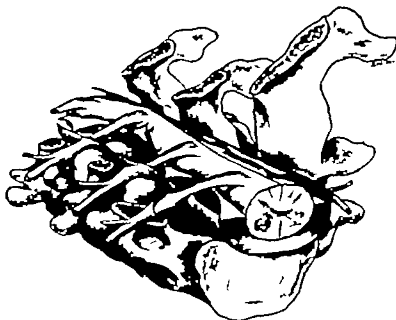


FIG. 335 Diagram showing how division of the dentate ligaments and posterior roots can allow the cord to "float" off the posterior surfaces of the vertebral bodies.



(a)



(b)

FIG. 336 Fusion of C4, 5, 6, 7 by two tibial grafts fixed to spinous processes by wire suture above and below. *Antero-posterior* and lateral radiographs



FIG. 337 Show g (*a*) Antero-lateral route to cervical spine. Behind, through, or in front of the sterno-mastoid retracting the great vessels, œsophagus and trachea forwards and passing across the front of the scalenes. This is a direct and relatively simple approach.



(*b*) Radiograph of patient with long-standing cervical spondylosis. As the result of a "whip-lash" injury dislocation with quadriplegia which was completely relieved by laminectomy. But the cervical spine was left unstable it was stabilized successfully by anterior fusion between C4 and the bodies below using a large iliac graft.



(*a*)



(*b*)

FIG. 336. Fusion of C4, 5, 6, 7 by twin tibial grafts fixed to spinous processes by wire suture above and below. *Antero-posterior and lateral radiographs.*



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Differential Diagnosis. There are of course causes other than cervical spondylosis for pain in the neck and arm and for the wide range of neurological symptoms and signs which may accompany this pain. Though cervical spondylosis is a common cause there are other *possibilities which fall into four headings*

1. Inflammatory and neoplastic lesions of the cervical spine.
2. Cervico-brachial syndromes, e.g. cervical rib
3. Carpal tunnel compression lesions of the median nerve
4. Disease of the central nervous system, e g disseminated sclerosis, etc.

It is necessary to consider these in more detail since, with disc lesions, they cover the whole problem and pattern of neck and arm pain accompanied by neurological disturbances—localized or widespread.

Inflammatory and Neoplastic Lesions of the Cervical Column and its Contents

These will be disclosed by comprehensive examination—clinical radiographic (Fig. 338) and by manometry of the cerebro-spinal fluid. For precise localization of tumours or other "space-occupying lesions myelography is usually essential and especially before exploration which is nearly always indicated.

Fig. 338. A malignant neoplasm of the body of the 4th cervical vertebra. Symptoms at first thought to be due to cervical spondylosis.

Lesions at the Cervico-brachial Outlet

At one time a cervical rib (Fig. 339) or its equivalent, helped by aberrations in the derivation of the brachial plexus was the sole explanation of pain and weakness in the hand. In comparatively recent times it has become obvious that accessory ribs could not be the only explanation, if for no other reason than that the syndrome of pain in the



FIG 339 Cervical rib arising from 7th cervical vertebra on one side On the other side the transverse process is larger than normal.

shoulder region radiating down to the hand is common while cervical ribs are rare. There are other hazards which the nerves to the upper extremity have to run before reaching the axilla. Furthermore having left the spinal column they are accompanied closely if not intimately by the main vessel to the limb so that the clinical picture to which pressure, stretching, or friction give rise may be a mixture of neurological and vascular signs and symptoms.

Clinical Picture

The characteristic symptoms and signs are

Pain usually felt along the inner aspect of the upper extremity in an area corresponding to the distribution of the medial cutaneous, median, and ulnar nerves. This is often

worse at the end of a hard-working day and especially in housewives between the ages of thirty and forty five the predominance in females of this age group is no doubt due to the normal descent of the shoulder girdle which occurs in middle age and to the constant shoulder movements associated with sweeping, dusting, overhead stretching, and all the other household chores.

Sensory Disturbances. *Hyperæsthesia, anæsthesia* but more often paræsthesia described as tingling, burning, numbness, pins and needles, along the inner side of the forearm and in the hand and fingers—usually in the ulnar nerve distribution. Occasionally paræsthesia (and pain) is present over the thenar eminence and the radial side of the hand and forearm—a median type of distribution.

Motor Disturbances. Atrophy of the small muscles of the hand occurs and progresses slowly Most commonly the intrinsic muscles supplied by the ulnar nerve are involved, but sometimes the thenar muscles (abductor pollicis brevis and opponens), or a combined median-ulnar distribution. This combination of involvement of ulnar and median nerves seems to be due to the fact that the lower plexus trunk contains all the fibres of the ulnar and the inner head of the median nerves

Sympathetic Disturbances. Excessive sweating has been noted and is thought to be due to irritation by the cervical rib, or its equivalent, of the sudomotor sympathetic fibres running in the lowest trunk of the plexus

Vascular Disturbances. Circulatory changes vary greatly in degree Most commonly the whole hand tingles or "goes to sleep," it feels cold or numb to the touch, and it appears bluish or pale in colour Emboli may produce patches of gangrene on the fingers. At the other end of the scale there is obliteration of the radial ulnar and part of the brachial pulse with gangrene of one or more fingers

Pathogenesis

The conceptions of the varied hazards which determine stretching, pressure or friction effects on the neuro-vascular bundle may be summarized briefly as physiological (muscle atony and "drooping" shoulder), anatomical (anomalies of bone, of nerve and of muscle attachments) and pathological (reactionary soft tissue changes)

(*a*) PHYSIOLOGICAL. Fatigue, unaccustomed manual work and the many hours spent in carrying shopping baskets result in atony of the shoulder girdle muscles, drooping of the shoulder and stretching of the plexus over the first rib or the anterior margin of the scalenus medius. It has been well known for many years that rest followed by graduated exercises to restore the power and tone of the shoulder girdle muscles will often relieve these symptoms even when a cervical rib is present.

These factors should always be considered when sorting out complaints of "tingling," "burning pains," and numbness and coldness in the fingers which are nowadays so common among middle-aged and elderly women.

(*b*) ANATOMICAL variations in the pathway of the vessels and nerves are an obvious source of pressure or stretching effects. This pathway—the cervico-brachial outlet or tunnel—can be altered in shape and in capacity by a number of factors It is continually altering with movements of the shoulder and arm. Accessory ribs may be present—the classical cervical rib first noted by Galen and later by Vesalius and admirably described in the present century by the anatomists Wingate Todd, Wood Jones, and

Stopford, and by surgeons, notably Sargent and Telford. The floor of the cervico-brachial tunnel is formed by the upper thoracic outlet which may be asymmetrical tilted and higher than normal because of lateral curvatures of the spine or because of mal development of the first rib, varying from rudimentary forms to alterations in the shape and the curve of the so-called normal. The potentialities for the exercise of stretching or friction effects are thus numerous. It is also claimed by Walshe and his co-workers that these structural anomalies of the upper thoracic outlet cause narrowing of the space between the clavicle and the first rib so that the neuro-vascular bundle can be nipped between the two bones when the limb is in certain positions—the costo-clavicular syndrome. That this is a common occurrence has been powerfully challenged by Telford and Mottershead. They point out that in a small proportion of cases the clavicle can compress the neuro-vascular bundle against the scalenus medius or an accessory or abnormal rib but only with the shoulder forcibly retracted backwards or the arm fully elevated in other positions there has been no sign of compression by the clavicle. Indeed these authors show that when the shoulder is depressed the clavicle moves downwards and forwards so that the costo-clavicular space is widened, not narrowed. The clavicle therefore cannot be responsible for the obliteration of the radial pulse which can occur when the shoulder is depressed by traction on the dependent arm. This is supported by the observation that when this manœuvre is carried out the axillary artery is not obliterated. Thus there must be some other cause for the disappearance of the radial pulse some compression occurring distal to the clavicle. It is thought that an anatomical disposition of the axillary artery in some individuals allows it to be squeezed between the lateral and medial heads of the median nerve when the shoulder is depressed (Fig. 340)

The anterior and medial scalene muscles and perhaps others may be involved in the production of lesions at the cervico-brachial outlet (Fig. 341) The fibrous, taut anterior border of the scalenus medius is a ridge over which the plexus can be stretched, particularly if the muscle attachment is carried unusually far forward on the first rib The scalenus anticus forms an angle with the first rib—the costo-scalene triangle in which lie the lower components of the plexus and the subclavian artery These can be compressed between the anterior scalene and a cervical rib especially if the attachment of the cervical rib to the first rib is prominent and bulky as it often is (Fig. 342) The situation is made worse if the insertion of the scalenus anticus is entirely tendinous, if it extends backwards in a falciform way and particularly if at the same time the tendinous insertion of scalenus medius is prolonged forwards unduly These anomalies of insertion of the two muscles distort the costo-scalene triangle and produce conditions where the inferior trunk of the plexus may be compressed or stretched. This is a passive and mechanical role and a much more satisfying explanation of how it comes about that division of the scalenes occasionally relieves patients suffering from the effects of pressure at the cervico-brachial outlet. The theory of isolated spasm of the scalenus anticus, to which the term "scalenus anticus syndrome" is applied, is difficult to understand. How it could arise in patients in whom fatigue and general muscular atony are otherwise outstanding features has never been satisfactorily explained, particularly since the muscle is supplied by the fourth fifth, sixth, and seventh cervical nerves well above the cervico-brachial outlet. Perhaps spasm of the scalenus anticus occurs more frequently in association with cervical spondylosis! One can visualize that one or more of its roots of supply could be irritated by encroachment of osteophytes on the exit foramina.

worse at the end of a hard working day and especially in housewives between the ages of thirty and forty-five the predominance in females of this age group is no doubt due to the normal descent of the shoulder girdle which occurs in middle age and to the constant shoulder movements associated with sweeping, dusting, overhead stretching, and all the other household chores

Sensory Disturbances. Hyperæsthesia, anæsthesia but more often paræsthesia described as tingling, burning, numbness, "pins and needles," along the inner side of the forearm and in the hand and fingers—usually in the ulnar nerve distribution Occasionally paræsthesia (and pain) is present over the thenar eminence and the radial side of the hand and forearm—a median type of distribution.

Motor Disturbances. Atrophy of the small muscles of the hand occurs and progresses slowly Most commonly the intrinsic muscles supplied by the ulnar nerve are involved, but sometimes the thenar muscles (abductor pollicis brevis and opponens), or a combined median-ulnar distribution. This combination of involvement of ulnar and median nerves seems to be due to the fact that the lower plexus trunk contains all the fibres of the ulnar and the inner head of the median nerves.

Sympathetic Disturbances. Excessive sweating has been noted and is thought to be due to irritation by the cervical rib, or its equivalent, of the sudomotor sympathetic fibres running in the lowest trunk of the plexus.

Vascular Disturbances. Circulatory changes vary greatly in degree Most commonly the whole hand tingles or "goes to sleep," it feels cold or numb to the touch, and it appears bluish or pale in colour Emboli may produce patches of gangrene on the fingers. At the other end of the scale there is obliteration of the radial, ulnar and part of the brachial pulse with gangrene of one or more fingers

Pathogenesis

The conceptions of the varied hazards which determine stretching, pressure or friction effects on the neuro-vascular bundle may be summarized briefly as physiological (muscle atony and "drooping" shoulder), anatomical (anomalies of bone, of nerve and of muscle attachments) and pathological (reactionary soft tissue changes).

(*a*) PHYSIOLOGICAL. Fatigue, unaccustomed manual work and the many hours spent in carrying shopping baskets result in atony of the shoulder girdle muscles, drooping of the shoulder and stretching of the plexus over the first rib or the anterior margin of the scalenus medius It has been well known for many years that rest followed by graduated exercises to restore the power and tone of the shoulder girdle muscles will often relieve these symptoms even when a cervical rib is present.

These factors should always be considered when sorting out complaints of "tingling," "burning pains," and numbness and coldness in the fingers which are nowadays so common among middle-aged and elderly women.

(*b*) ANATOMICAL variations in the pathway of the vessels and nerves are an obvious source of pressure or stretching effects. This pathway—the cervico-brachial outlet or tunnel—can be altered in shape and in capacity by a number of factors. It is continually altering with movements of the shoulder and arm. Accessory ribs may be present—the classical *cervical* rib first noted by Galen and later by Vesalius and admirably described in the present century by the anatomists Wingate Todd, Wood Jones, and

Stopford and by surgeons, notably Sargent and Telford. The floor of the cervico-*brachial tunnel is formed* by the upper thoracic outlet which may be asymmetrical tilted and higher than normal because of lateral curvatures of the spine or because of maldevelopment of the first rib varying from rudimentary forms to alterations in the shape and the curve of the so-called normal The potentialities for the exercise of stretching or friction effects are thus numerous. It is also claimed by Walshe and his co-workers that these structural anomalies of the upper thoracic outlet cause narrowing of the space between the clavicle and the first rib so that the neuro-vascular bundle can be nipped between the two bones when the limb is in certain positions—the costo-clavicular syndrome. That this is a common occurrence has been powerfully challenged by Telford and Mottershead. They point out that in a small proportion of cases the clavicle can compress the neuro-vascular bundle against the scalenus medius or an accessory or abnormal rib but only with the shoulder forcibly retracted backwards or the arm fully elevated in other positions there has been no sign of compression by the clavicle Indeed these authors show that when the shoulder is depressed the clavicle moves downwards and forwards so that the costo-clavicular space is widened not narrowed. The clavicle therefore cannot be responsible for the obliteration of the radial pulse which can occur when the shoulder is depressed by traction on the dependent arm. This is supported by the observation that when this manœuvre is carried out the axillary artery is not obliterated Thus there must be some other cause for the disappearance of the radial pulse some compression occurring distal to the clavicle It is thought that an anatomical disposition of the axillary artery in some individuals allows it to be squeezed between the lateral and medial heads of the median nerve when the shoulder is depressed (Fig. 340)

The anterior and medial scalene muscles and perhaps others may be involved in the production of lesions at the cervico-brachial outlet (Fig. 341) The fibrous, taut anterior border of the scalenus medius is a ridge over which the plexus can be stretched, particularly if the muscle attachment is carried unusually *far forward on the first rib* The scalenus anticus forms an angle with the first rib—the costo-scalene triangle in which lie the lower components of the plexus and the subclavian artery These can be compressed between the anterior scalene and a cervical rib especially if the attachment of the cervical rib to the first rib is prominent and bulky as it often is (Fig. 342) The situation is made worse if the insertion of the scalenus anticus is entirely tendinous, if it extends backwards in a falciform way and particularly if at the same time the tendinous insertion of scalenus medius is prolonged forwards unduly These anomalies of insertion of the two muscles distort the costo-scalene triangle and produce conditions where the inferior trunk of the plexus may be compressed or stretched. This is a passive and mechanical role and a much more satisfying explanation of how it comes about that division of the scalenes occasionally relieves patients suffering from the effects of pressure at the cervico-brachial outlet. The theory of isolated spasm of the scalenus anticus, to which the term "scalenus *anticus syndrome" is applied, is difficult to understand. How it could* arise in patients in whom fatigue and general muscular atony are otherwise outstanding features has never been satisfactorily explained particularly since the muscle is supplied by the fourth, fifth, sixth, and seventh cervical nerves well above the cervico-brachial outlet Perhaps spasm of the scalenus anticus occurs more frequently in association with cervical spondylosis! One can visualize that one or more of its roots of supply could be irritated by encroachment of osteophytes on the exit foramina.

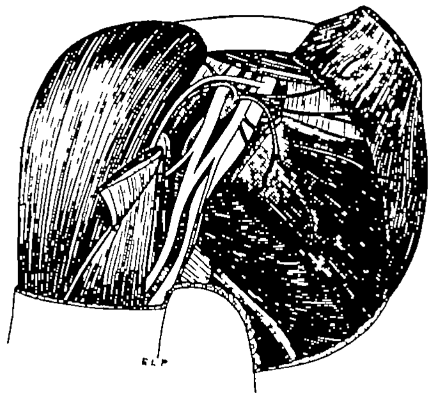
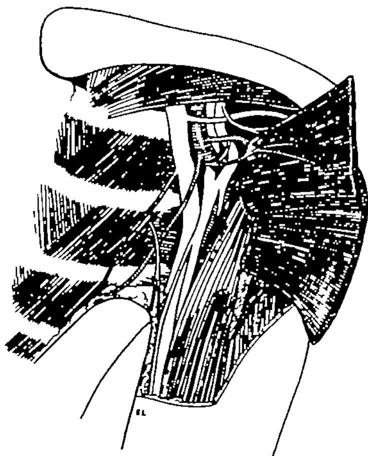


FIG. 340 (*a*) Arrangement of the nerves relative to the artery which renders impossible any compression of the vessel between the two heads of the median nerve—found in twenty out of fifty-four dissections.



(*b*) Disposition of nerves relative to the axillary artery in cases where depression of the shoulder causes arrest or diminution of the radial pulse—found in thirty-four out of fifty-four dissections.

(By kind permission of Messrs. E. D. Telford and S. Mottershead and the "Journal of Bone & Joint Surgery"—British number. E. & S. Livingstone, Ltd.)

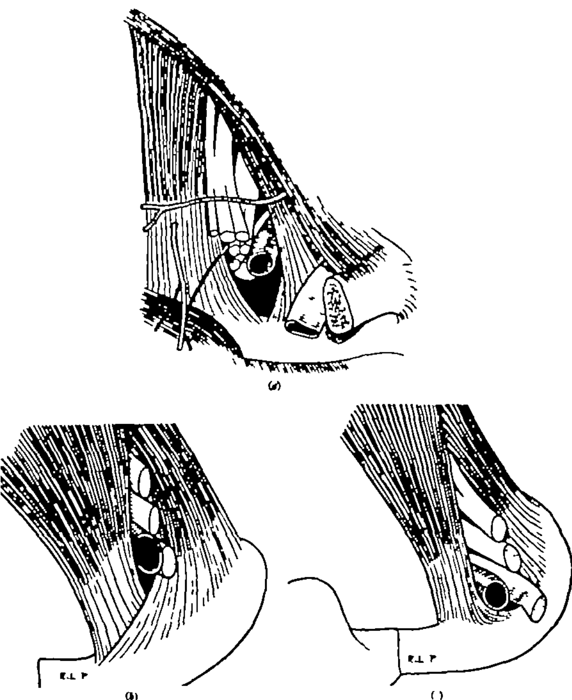


FIG. 341 (a) The normal pattern of insertion of the scalenus anterior and scalenus medius.
(b) Scalenus medius insertion carried unusually far forwards on first rib. It overlaps the insertion of scalenus anterior forming V and obliterating the costo-scalene angle.
(c) The rare falciform type of insertion of scalenus anterior

(By kind permission of Messrs. E. D. Telford and S. Mottershead and the "Journal of Bone & Joint Surgery"—British number E. & S. Livingstone Ltd.)

(c) PATHOLOGICAL. Wear and tear of the tissues in the cervico-brachial tunnel is yet another factor in producing symptoms. Unceasing respiratory movement of the thorax and the frequent arm and shoulder movements of everyday life must aggravate existing maladjustments between nerves, arteries, and bones. This oft-repeated friction, stretching and compression of soft tissues leads to considerable reactionary tissue

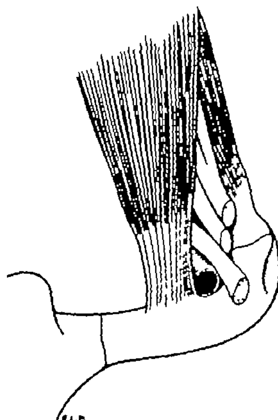


FIG. 342. Compression of the subclavian artery and inferior trunk of the plexus between scalenus anterior and the forward end of a cervical rib.

(By kind permission of Messrs. E. D. Telford and S. Mottershead and the "Journal of Bone & Joint Surgery"—British number E. & S. Livingstone, Ltd.)

changes as age increases. Thus the walls of the subclavian artery may become worn and the artery may be bound to the first rib or the cervical rib by scar tissue which can also drag on the nearby stellate ganglion, already tethered to the artery by the annulus of Vieussens. This perhaps explains some of the sympathetic phenomena which are occasionally encountered, e g. Horner s syndrome

While it is not difficult to understand how the nerve trunk is usually involved, the mechanism of involvement of the main vessel to the limb is still by no means clear The changes observed are thrombosis of the brachial artery distal to the lower border of the pectoralis major without obvious abnormality in the subclavian artery In a smaller

proportion of patients with vascular complications there are gross changes in the subclavian vessel distal to the cervical rib—a thrombosed aneurysmal dilatation with much periarteritis. It has been suggested that these changes are brought about by repeated nipping of the vessel between the abnormal rib and the clavicle resulting in dilatation aneurysm, thrombosis, and peri-arterial fibrosis. Telford and his co-workers still consider that irritation, by chafing over the cervical rib of the leash of undistributed sympathetic fibres present in the lower trunk of the plexus causes intermittent arterial spasm and leads eventually to thrombosis in the brachial artery. For aneurysmal dilatation of the subclavian vessel itself he postulates a different mechanism. The sequence is a simple dilatation without thrombosis, and later rapid thrombosis in the dilatation due to sudden rupture of the intima. It seems likely that the aneurysm results from frequent nipping between the accessory rib and the clavicle by strong oft repeated retractions of the shoulder with the arm at the right angle, e.g. in playing hand-ball, tennis racquets, etc. There is still considerable controversy about how this nipping of the vessel actually produces dilatation distal to the source of injury. Some suggest that the vessel wall is weakened by damage to its nutritional supply—the vasa vasorum. Others feel that repeated nipping causes paralysis and degeneration of the vaso-motor nerves with secondary stretching and dilatation of the denervated middle coat—a process which could extend distally beyond the site of nipping as far as the entrance point of the next relay of uninjured vaso-motor fibres.

Treatment. In the usual lesion without vascular complications conservative measures are worth trying first—support in a triangular sling or on a shoulder abduction frame followed by shrugging and bracing exercises to strengthen the suspensory muscles of the shoulder girdle. Operation is urgently advisable when circulatory changes occur and when conservative treatment fails to give relief from the other manifestations of cervical rib syndromes. Since the causes of pressure on the neuro-vascular bundle are many and varied it is wise to make an exposure sufficiently wide to allow comprehensive investigation of the area so that any of the various causative factors can be dealt with adequately by excision of bone, or incision of tight fibrous bands or tendons.

Carpal Tunnel Compression Lesions

This syndrome was first clearly described by Russell Brain and Dickson Wright in 1947. It results from compression of the median nerve in the carpal tunnel and there are many causes, some of which cannot at present be identified. Any lesion which narrows the tunnel is likely to cause median nerve compression, e.g. tenosynovitis, ganglion, persistent dislocation of the semilunar rheumatoid and osteoarthritis, and conditions which cause thickening of the transverse carpal ligament.

Commonly the condition occurs in middle aged individuals, usually women, who complain of numbness, tingling, burning, "pins and needles" in the median distribution in the hand, worse after effort and paradoxically at night to an extent where sleep is disturbed. In the morning the fingers feel stiff and puffy which is probably due to a co-existing tenosynovitis. Some pain may radiate up the forearm and arm but it is rarely severe.

Examination in the well-developed lesion presents a classical picture of median nerve involvement—impairment of sensation in the thumb index, middle and half the ring finger wasting of the radial two-thirds of the thenar eminence and weakness of the

Logue, Valentine (1951) "Cervical intervertebral disc protrusion," *Postgraduate Medical Journal* XXVI 636.

Martin, G M. and Corbin, K. B. (1954) "An evaluation of conservative treatment for patients with cervical disk syndrome," *Proceedings of the Mayo Clinic* 29 11 324

Von Luschka, H (1858) Die Halbgelenke des Menschlichen Körpers. C *Reimer* Berlin.

Walshe, F M R. *et al* (1944) "On some pressure effects associated with cervical and with rudimentary and 'normal' first ribs," *Brain*, 67 3 141

*Telford, E. D and Mottershead, S. (1948) "Pressure at the cervico-brachial junction," *J Bone Jt Surg.*, 30B, 2, 249

A complete survey of the literature is given in these papers.

Abductor Pollicis Brevis and Opponens Pollicis muscle. Unfortunately there are many patients in whom it is difficult because of lack of physical signs to make a diagnosis which then depends on an accurate account of the distribution of paraesthesia and failure to establish any other cause. If symptoms persist in spite of simple splinting and modification of activities, relief can be obtained by dividing the transverse carpal ligament through a short longitudinal incision between the thenar and hypothenar eminences, extending proximally to the distal crease across the front of the wrist. Causative lesions which lend themselves to removal e.g. ganglion, exostoses, should be removed at the same time.

Disease of the Central Nervous Systems

Scarcely any of the conditions under this heading come within the scope of orthopaedics except in so far as assistance can be given by splinting, an occasional stabilizing operation, and an occasional amputation. Disseminated sclerosis, amyotrophic lateral sclerosis syringomyelia, and other conditions causing neurological changes in arms, trunk, and legs require most careful neurological assay Difficulties are not made easier by the fact that any of these conditions may be—and indeed after middle age usually are—accompanied by radiological changes of cervical spondylosis.

A study of the differential diagnosis of pain in the neck and arm shows that the problems most difficult to distinguish from symptom-producing cervical spondylosis are lesions at the cervico-brachial outlet and median carpal tunnel compression syndromes. The latter if clear-cut offer no great problem. Nor does cervical spondylosis when the fifth and sixth or seventh roots are involved. It is precisely in those lesions where overlap in clinical pictures is so common that real difficulty arises. In my view it is nearly impossible to distinguish the clinical picture produced by cervical spondylosis causing C8–D1 root symptoms from that due to a lesion of the lower trunk of the plexus at the cervico-brachial outlet. The most one can say is that objective signs at one level with nothing convincing at the other area of suspicion, e.g. a cervical rib with minimal changes of cervical spondylosis, may assist in arriving at a correct diagnosis and appropriate treatment.

I would like to acknowledge help from many quarters. The generosity of other writers in this field—Sir Russell Brain and his co-workers, Professor Telford and co-workers, Dr J D. C. Bull, Mr Valentine Logue and the various journals concerned—in allowing me to use their illustrations has made repetition unnecessary I am greatly indebted to my orthopaedic colleague Mr J N Aston, F R.C.S., for his beautifully executed drawings and to Mr R. F Ruddick of the Department of Clinical Photography at the London Hospital for reproducing them and X-ray reprints so clearly

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Von Luschka, H. (1858) Die Halbgelenke des Menschlichen Körpers. *C. Reimer* Berlin.
Walshe, F. M. R. *et al.* (1944) "On some pressure effects associated with cervical and with rudimentary and 'normal' first ribs," *Brain*, 67 3 141
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A complete survey of the literature is given in these papers.

CHAPTER XVIII

ANTERIOR POLIOMYELITIS

R. H. C. ROBINS AND NORMAN CAPENER

ANTERIOR poliomyelitis is the name given to an acute virus disease, characterized by a feverish illness with meningeal symptoms which may be followed by paralysis. The virus concerned has a special affinity for the grey matter (polio = grey) of the spinal cord, which accounts for a flaccid paralysis of lower motor neurone type. While this is the typical course taken, it is known that most patients have more or less widespread lesions throughout the central nervous system, and in consequence a number of variations are found depending upon the extent and distribution of the neurones affected.

The main concern of the orthopaedic surgeon is with the effects of the disease rather than with its primary pathology. It is none the less important that he should be consulted from the onset, for the successful management of the severely affected patient in the acute stage depends upon close co-operation between the orthopaedic surgeon and the general physician.

Epidemiology

Poliomyelitis is an ancient disease. Recognizable descriptions of the condition and portrayals of the late deformities are found in the literature and sculpture of early civilizations, but Underwood's account, the first to define it with certainty, did not appear until 1784. Heine differentiated poliomyelitis from other similar diseases in 1840 and in 1887 Medin recognized it as a disorder of the central nervous system. The great epidemic in the United States of America during 1916 brought it to the serious notice of the general public, and since then it has remained in the forefront of medical topics to the profession and to the laity alike.

Poliomyelitis is caused by a virus of diameter 8–12 μ, which is sensitive to desiccation and destroyed at temperatures over 60°C. Several strains are known to exist, and three immunological types (Brunhilde—Lansing—Leon) have been identified. Much of our present knowledge is based on the pioneer work of Landsteiner and of Flexner, who proved the etiology of the disease by its serial transmission in monkeys. Although the virus has been found in the blood and cerebro-spinal fluid of monkeys, it has not been identified with certainty in these media in patients in the acute paralytic stage of the disease. It is, however, present in the pharyngeal secretions and in the faeces of patients and also of contacts who have developed no symptoms. It follows that such contacts are carriers of poliomyelitis and thereby are liable to infect others.

Poliomyelitis occurs in endemic and in epidemic forms, the latter being prevalent in the later summer months. During recent years the disease has been attacking a greater proportion of the adult population and with increasing age the mortality has been higher. Medical opinion on the epidemiology of poliomyelitis is constantly changing. The

following views accord with our present state of knowledge, but it is likely that the next decade will see the need for modification.

From a study of circumscribed epidemics, it seems well established that the disease is mainly transmitted by human contact, often through the intermediary of carriers who never themselves develop the disease in clinical form. The portal of entry is usually the mouth, and the primary site of infection is in the mucosa of the pharynx and alimentary tract, where the virus multiplies. Large quantities of virus can be recovered from the stools of patients as much as one million infectious doses for monkeys may be detected in a gram of faeces.

It is not proven how the virus spreads from the alimentary tract to the central nervous system. Until recently it was generally held that it was along the nerve fibres, and it is still possible that this is the route taken when bulbar poliomyelitis is a sequel to tonsillectomy but experimentally the detection of virus in the blood in the pre-paralytic stage in humans and experimental monkeys offers a more likely explanation. This is supported by observations of the widespread nature of the pathological changes in tissues outside the nervous system.

The incubation period is usually seven to fourteen days, but it may be as short as three days or as long as five weeks. Twenty-one days is regarded as a safe period for quarantine.

The immunology of poliomyelitis is receiving much attention. Antibodies have been identified in the blood of monkeys and of man, and on this basis methods of active immunization by vaccine or by attenuated living virus have been developed. Injections of convalescent serum or of gamma globulin confer passive immunity for a few weeks. Impracticable for mass use, these should be reserved for special contacts as for example those in a closed community such as an infant school.

Apart from immunization, prophylaxis against the disease includes quarantine and the isolation of the patient and contacts. In our present society this implies a considerable social and economic disruption and it is not yet known how effective these measures may be we await the results of several public health schemes now in operation. Meanwhile, when epidemics threaten it is reasonable to institute quarantine precautions for children who have been close contacts, to keep from work those contacts who handle food in shops or restaurants, and to impress upon all such persons the importance of hygienic measures after the use of the toilet.

Pathological Changes

Our knowledge of these changes is derived from experimental work on monkeys and post mortem studies in man, and many of the recent advances are associated with the name of Bodian. Patients who have died as a result of the disease show a generalized hyperplasia of the reticulo-endothelial system, but the principal pathological changes are found in the central nervous system and in the muscles.

(1) **Changes in the C.N.S** Although the principal site of involvement is the grey matter of the spinal cord, all cases of poliomyelitis show microscopic lesions in the brain-stem and motor cortex (Harbitz and Scheel 1907). In the face of the known histological facts, the infrequency with which patients in the acute stage show signs of cerebral involvement underlines the great margin of safety found in the central nervous system. It has, however been suggested that the meningeal signs, which are almost a constant

clinical finding, are due to affection of the sub-cortical centres. Clinically important is the observation that the neurological lesions occur in the pre-paralytic stage of the disease. Histologically the largest motor neurones are seen to be attacked. The earliest changes are a diffuse chromatolysis of the Nissl substance in the cytoplasm of the nerve cells, which is accompanied by an inflammatory reaction, first of polymorphonuclear leucocytes and later of lymphocytes. The former soon disappear but the latter persist as a perivascular cuff. The changes in the cells may be present without any surrounding inflammatory reaction, and are therefore due to a direct action of the virus and are not secondary to oedema and vascular changes. The nerve cell may be totally destroyed and undergo phagocytosis by the neuroglia, or the process may be arrested at the stage of chromatolysis. The changes are then reversible, recovery taking place within one month. *The clinical application of this is evident: early recovery in the course of poliomyelitis is due to this process. The destroyed nerve cell has no power of regeneration and the degree of paralysis is proportional to the number of motor nerve cells so affected. Later recovery in the disease is thus due to hypertrophy of non-paralysed muscle fibres.*

(2) **Changes in the Muscles.** Paralysed muscles show atrophy, degeneration and fibrous replacement similar to those in the later stages of a peripheral nerve injury. Muscles which clinically are less involved also show these changes and their nature suggests the presence of some intrinsic myositic element, as an additional factor. Further support to this theory is provided by evidence of a disordered physiology at the neuromuscular junction.

One of the clinical characteristics of poliomyelitis in the early stage is "muscle spasm." Electromyography has shown that this is due to hyper-irritability of the muscle in its resting stage. Whatever its basic cause, spasm is found in unaffected and in weak muscles, but it is absent in those which are completely paralysed: its presence therefore indicates some power of recovery.

Distribution of Paralysis

Recent work by Sharrard has shed light on the distribution of paralysis in poliomyelitis. Analysing in a large series of cases the muscles affected, whether paralysed or paretic, he was able to determine the ratio of paresis to paralysis and thus the susceptibility of any given muscle to paralysis. For example, the tibialis anterior was paralysed in two patients for every one in whom it was weak: the reverse was true of the quadriceps which showed a ratio of one paralysed to three paretic. Furthermore, paralysis in the lower limb was found to follow certain patterns although muscles which were associated by being paralysed or spared together were as often totally unrelated as of like function. The solution to this clinical pattern was found by careful pathological examination of poliomyelitic spinal cords, which not only led to the localization of function in the anterior horn cells in man, but also demonstrated the focal destruction produced by the disease. Thus those muscles with a short segmental innervation, such as tibialis anterior were more liable to have all their motor cells destroyed than those such as quadriceps femoris with a spinal representation extending longitudinally through several segments.

Autonomic Changes

Profound vascular changes are often found in a paralysed limb. These may take the form of circulatory changes in the skin with trophic ulceration or of disturbances at the

epiphysis. In the early stages of widespread paralysis the bladder and the bowel are often included, although recovery is the rule. These effects may be caused by damage to the autonomic centres in the brain or spinal cord, or they may be secondary to muscular inactivity: it is probable that both factors play a part.



FIG. 343 Radiographs to illustrate atrophic changes in the skeleton with bony deformity associated with unbalanced muscular action unprotected from the effects of gravity: genu valgum and genu recurvatum.

Clinical Picture:
Acute Stage

Poliomyelitis characteristically presents as an acute, febrile illness with meningitic symptoms, shortly followed by paralysis. Although occasionally it may be insidious, the onset of the acute illness is usually abrupt. In any event, its seriousness soon becomes evident and Horstmann (1950) has termed this the major illness. About 40 per cent of patients have a preceding minor illness. This is of a catarrhal nature and a few days of malaise is followed by a brief period of normal health. The symptoms are probably due to the presence of the poliomyelitis virus in the blood stream. Many patients do not proceed to the major illness and they constitute the abortive cases of poliomyelitis. The frequency of the minor illness is not known, because it is likely to pass unnoticed in the absence of an epidemic.

Major Illness. Pre-paralytic Stage. The poliomyelitis virus is now in the central nervous system and in the course of a few hours or days the fate of the motor nerve cells is decided. The onset is acute and is often accompanied by nausea and vomiting. There is a moderate fever and considerable malaise. Pain in the trunk, particularly the neck and back, is an almost constant complaint and similar symptoms may be referred to the limbs, where paræsthesiæ are sometimes felt. The clinical signs of meningeal irritation appear early but they are less marked than those found in meningitis. Stiffness of the neck for example, may pass unnoticed unless the examination is carried out with care and gentleness. Headache is prominent but not severe and the mental clarity of poliomyelitis contrasts with the confusion and drowsiness which characterize most other acute infections of the central nervous system. Kernig's sign is usually positive and stiffness of the back prevents the patient from kissing his knees.

Great variations in the clinical picture are encountered, but there are always sufficient indications to lead to a provisional diagnosis, which should be confirmed by lumbar puncture. It is emphasized again that paralysis is not essential to the diagnosis.

The cerebro-spinal fluid shows an increase in the cell count, which may range from 10 cells to over 500 per cm. In the early stages, up to 85 per cent of these may be neutrophils. With the progress of the illness, the cell count falls and lymphocytes predominate. The total protein rises (sometimes to 500 mg. per cent or higher) after two or three weeks, and returns to normal at about six weeks, by which time the cells may have disappeared

Major Illness. Paralytic Stage. After a few days, paralysis may occur and make the diagnosis obvious. It is a flaccid paresis of lower motor neurone type which usually reaches its maximum within 3 days. The tendon reflexes and the plantar response are diminished or absent. It is important to note that there are no sensory changes. Muscle pain and tenderness are often prominent. Loss of power may affect all or any of the four limbs, it may be symmetrical or asymmetrical and it may be of any degree of severity Respiratory paralysis is particularly dangerous.

The above account is of a typical case. Less commonly the pre paralytic phase is very brief paralysis being almost the first manifestation of illness. Patients who are seen with pareses affecting a few muscle groups and apparently of spontaneous onset usually admit to symptoms of a preceding minor illness on further enquiry

Special Types of Poliomyelitis

Clinical involvement of the brain-stem or cerebral cortex gives rise to a clinical picture in which different features predominate. In the brain-stem paralytic group (commonly called bulbar) there is weakness of muscles supplied by the cranial nerves, or paralysis of the respiratory or circulatory centres. Bulbar poliomyelitis may represent the only paralytic manifestation of the infection, or it may supervene as the final stage in the progression of a spinal paralysis.

Cranial nerve involvement may cause nystagmus, ophthalmoplegia or facial weakness, but the important features are paralyses of the pharynx and larynx. These paralyses lead to inability to swallow to obstruction of the air way and to aspiration of secretions into the lungs. If the condition is not recognized, and the association of pharyngeal paralysis with cyanosis is thought to be due to respiratory weakness, it may lead to disaster the patient being placed in a respirator and mucus being forced into the lungs under pressure.

Failure of respiration may occasionally be due to paralysis of the centre. The characteristic feature is the decrease in the rate and depth of respiration despite strong respiratory muscles and a good airway This is followed by periods of apnoea and Cheyne Stokes breathing. In paralysis of the circulatory centre vasomotor collapse, characterized by a rising pulse and a falling blood pressure, is the predominant clinical finding.

In the cortical (encephalitic) group, restlessness and confusion dominate the picture and may lead to a mistaken diagnosis of meningitis or encephalitis. Experimentally it has been shown that many of these symptoms are not truly encephalitic, but are due to hypoxia resulting from brain-stem involvement. They may then be abolished by improved oxygenation. A certain proportion, however are of cortical origin, but this diagnosis should probably be reserved for those patients who show some evidence of true spasticity in the limbs.

Autonomic Involvement

The main complications are paralysis of the bowel and bladder but these are usually transient.

Causes of Respiratory Embarrassment

The causes of this may now be summarized

(1) Paralysis of the intercostal muscles and diaphragm, due to lesions in the spinal cord. This is relatively common and is usually associated with widespread pareses in the limbs. In adults there is a special association with weakness of the deltoid muscle.

(2) Paralysis of the respiratory centre. This is rare and often fatal.

(3) Pharyngeal paralysis. It is imperative to diagnose this when present. The treatment is fundamentally different, and, moreover recovery when it occurs is usually complete

All these groups may be complicated by the development of pneumonia.

Factors Affecting the Prognosis

Two factors increase susceptibility to the disease and a third materially influences its course. The development of bulbar poliomyelitis on infection with the virus is more likely after recent tonsillectomy or even dental extraction. Immunization or indeed any form of intra-muscular injection may predispose to the development of paralysis in that limb

Clinical studies have conclusively shown that exercise and activity with their associated fatigue are the main factors which determine the severity of the paralysis. It is certain that after the onset of the acute stage exercise is particularly dangerous it may also be harmful before the major illness has started.

Practically all the early deaths from poliomyelitis are attributable to brain-stem involvement.

To return to the main clinical picture, the subsidence of the feverish illness and the presence of paralysis usher in the convalescent stage.

Convalescent Stage

The period from the end of the febrile illness until the time when no further recovery is to be expected marks the extent of the convalescent stage. In practice it starts about

be facilitated by aspiration, and in the rare cases of total laryngeal paralysis tracheotomy must not be delayed, as this may well be a life-saving measure

Special nursing" is essential for these patients, and gastric feeding through a nasal catheter is often necessary Adequate sedation is important and oxygen may be helpful.

Bulbar poliomyelitis associated with weakness of the respiratory muscles is a difficult combination which requires the use of a respirator in addition to postural treatment.

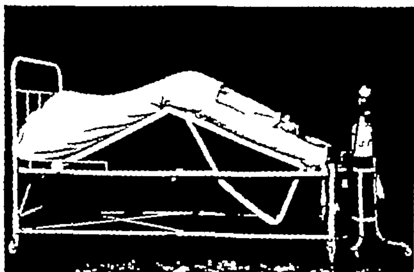


FIG 348. Postural bed for (i) Management of patient with paralysis of swallowing. ( ) Drainage of chest in patients with inadequate cough. *Note* the removal of head of the bed to give ready access to the patient's face oxygen cylinder with suction attachment The bed can also be tilted laterally I the absence of special equipment either simple tilting of the bed on chairs or an elevator or the knee bend of a Fowler bed can be used.

(From Handbook on Poliomyelitis, Trueta, Kinnier and Agerholm, Blackwell Scientific Publications, Oxford)

Types of Respirator The main varieties in general use are

(1) Tank respirator *In this the whole body except the head, is enclosed and negative and positive pressures are applied intermittently It is the most widely distributed machine in use in Great Britain today*

(2) Cuirass respirator *This acts by intermittent compressions of the chest and is of most use in mild, chronic cases of respiratory weakness, and in weaning the patient from a tank respirator Judiciously used, it is a form of assisted active exercise for the respiratory muscles, helping to prevent rigidity of the thoracic cage.*

(3) Positive pressure respirator *This is a recent development. The machine is portable and is used with an inflatable catheter inserted through a tracheotomy It permits very delicate adjustment of the rate and depth of breathing, and the patient is not "enclosed."*

When respirators are in use, the nursing difficulties are increased and patients should never be left unattended. Ambulance men must be aware of bulbar involvement when transporting patients with poliomyelitis and familiar with the principles of postural treatment and artificial respiration.

Management in the Convalescent Stage

Throughout this stage, regular estimations of muscle power are needed, and in the early weeks the degree of tenderness and muscle spasm should be assessed daily A method of grading of muscle strength has been recognized in Great Britian by the Medical Research Council. Muscles which show no contraction are classed as 0 while those whose action is normal are 5 A flicker is 1 a definite contraction 2, ability to sustain a contraction against gravity 3 and a contraction against both gravity and resistance 4 The prognostic value of this analysis has recently been shown by Sharrard s observations on the recovery of paretic muscles. For example, every muscle in the lower limb which is not completely paralysed at 4 months from the onset of the disease may be expected to increase in power by one grade before its final state is reached.

Sir Robert Jones in England and Robert Lovett in Boston were the pioneers in the orthopædic management of poliomyelitis. The guiding principles are to aid natural recovery and to prevent contracture and deformity In the sensitive stage attempts are made to diminish spasm, while during the long non sensitive period attention is directed to the retraining of such motor units as remain, and to the social and economic rehabilitation of the patient.

Modern methods seek to maintain a balance between the need for rest and support and the need for mobility Sister Elizabeth Kenny performed a service to humanity not so much by her methods of treatment, but by stimulating the work and thought of others. Her pathology was unsound and there was little that was new in her methods but she succeeded in shaking orthodoxy out of complacency Much of her special treatment had been anticipated by Peabody Draper and Dochez in 1912 and by Legg in 1924 Her greatest contribution was her outcry against the rigid splinting which had become all too frequently the accepted practice.

The Sensitive Phase. Skilful nursing is still very important. Particular attention is paid to adequate fluid intake, and to the prevention of constipation. The maintenance of the physiological position at rest is the responsibility of the nursing staff. The physiotherapists and the nursing staff perform passive movements several times daily to increase the range of joint motion. Early contractures may be gently stretched but no part of the limb should be forced out of a position of deformity correction must be gradual. Plaster of Paris splints for the wrists and feet are often helpful, particularly for night use. Where "muscle spasm" is marked, short periods with hot packs or immersion in saline baths are often beneficial and gentle massage may also be used, particularly as a prelude to passive supported movements. For muscle groups less seriously affected, assisted, active exercises are performed within the tolerance of fatigue. Breathing exercises and changes of posture are important. Although technically difficult, all these methods of treatment should be employed for patients whose respiratory embarrassment demands the continued use of the respirator

The Non-sensitive Phase. Routine examination by the orthopædic surgeon is needed at least weekly of in patients and less frequently of out patients. At each visit, the patient is examined for evidence of recovery and for the presence of deformity In a child, special study of the spine must be given, and the length of the lower limbs measured. It is helpful for the muscles to be charted every 3 months preferably by the same person on each occasion During the course of this period, the mildly affected

patients will regain normal activity and for those severely affected rehabilitation must be planned.

Treatment aims (1) at preventing contracture and deformity and (2) at retraining muscle power Contractures are prevented by maintaining the correct posture of the limb and by keeping a full range of passive movement at all joints. In the growing child there is continual need for vigilance, and muscles showing a tendency to contracture must be stretched daily Parents often need to be instructed in the performance of this the calf muscles are most frequently affected. The problem of paralytic scoliosis is discussed elsewhere, but mention may be made here of the value of daily stretching in a net, by the method of le Mesurier which contributes to the maintenance of mobility in the spine.



FIG. 349 An adult with untreated paralytic deformity of foot dating from anterior poliomyelitis in infancy

The development of muscular power depends on active exercises supervised by the physiotherapist and subsequently continued by the patient at home. Care must be taken to avoid fatigue or to favour strong muscles at the expense of the weak. The brine bath is valuable for supporting weak muscles against gravity Exercises in the immersion pool are performed with greater ease and better relaxation is thus obtained. Moreover the method is of immense psychological value.

In deciding when patients should become ambulant, distinction must be drawn between adults and children. With adults, unprotected weight bearing is usually permissible within 9 months from the onset of the disease, sometimes earlier With regard to the prognosis in individual muscle groups, complete absence of contraction after 3 months indicates that the loss of function is probably permanent and therefore that continued protection from weight bearing is unlikely to help

In children, however the factor of growth is all important. Until the child is fully developed, there is always the need to control growing bone and to protect joints. For example, the deformity of genu recurvatum is due almost entirely to over-stretching the posterior capsule of a joint with inadequate extensor muscular control For these reasons, children with severe weakness in the lower limbs are usually prevented from unprotected weight bearing. No brace will fully control a paralytic scoliosis and children thus affected should be kept down in recumbency most of the time during the first year

The principles of appliances in orthopaedics have already been mentioned in the opening chapters. In rehabilitation, the loading of patients with appliances should be avoided as far as possible. While these may be necessary in the growing period the eventual aim should be to devise means, surgical if necessary to remove them.

Splints for children are not only ambulatory aids, providing stability and substituting for absent muscle power but *they are also essential in controlling deformity* Distinction must be drawn between rigid and mobile splintage A rigid splint simply confers stability whereas a mobile or lively appliance has some of *the characteristics of muscular action* and indeed may materially assist weakened muscle-groups. Among the splints most commonly used is the long walking caliper with or without a pelvic band, according to the strength of the hip muscles a joint at the knee is often provided to allow for flexion when sitting down, and to lock in extension when the patient is standing.

The flail foot may be controlled by a box joint to the caliper or by back stops, both of which will have a rigid effect, or by balanced springs which allow for mobility The Exeter coil principle successfully compensates for the drop-foot. In the upper limb the lively abduction frame is used for deltoid paralysis. Many of the varieties of hand splints already described play a useful part.

In helping a patient to become ambulant patterns of sitting and walking are taught. Axillary crutches give place to elbow crutches and these, in turn, to sticks, while con fidence in walking without external aids is gained with practice between parallel bars. *All rehabilitation must take account of ambulation and the management of stairs.* It must aim to make the patient independent, able to rise from a chair to dress himself and to go to toilet. The use of his hands must be encouraged, and for this occupational therapy is helpful. By the time that he is ready to leave hospital, plans for future work or re training should already have been made.

Management in the Chronic Stage

Although an assessment of permanent weakness and disability may now be made, regular follow-up examinations at after-care clinics are desirable for adults and essential for children. Appliances need to be checked from time to time, and adult patients require guidance in their adjustment to life as disabled persons. In children the watch for con tracture and deformity is continued and observations are made of disparity in growth Those who develop paralytic scoliosis require radiological examination of the spine every six months in order that any deterioration may be determined precisely

As in the earlier months, contractures in children are forestalled by regular stretchings and exercises and by the proper provision of appliances. These methods do not always succeed, particularly with regard to the calf muscles. Operation, however is not needed for lesser degrees of contracture, which will respond to slow stretching in plaster or other forms of splint. Stretching of the calf may be accomplished by one of the methods used in correcting the relapsed congenital club-foot. Likewise, a fixed flexion deformity of the hip may often be relieved by the slow stretching method described by Dame Agnes Hunt.

Muscular weakness may be overcome by

(1) *The use of the secondary action of certain muscles and the development of trick movement* (e.g. the hip extensors or the calf to extend the knee, a function that may be aided by some degree of fixed equinus in the foot). This is the patient s spontaneous method.

(2) *Appliances*

(3) *Operation.*

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The Principles of Surgical Reconstruction in Poliomyelitis

Operations for the residual effects of poliomyelitis may have three aims

(1) *Correction of deformity or growth disparity*
(2) *Restoration of muscle balance*
(3) *Stabilization of joints*

The improvement of muscle balance and the conferring of stability may remove the need for external support. Very few operations are restricted to one of these purposes in the foot, for example, all three aims may be fulfilled by one operation.

The problems of reconstructive surgery in poliomyelitis are similar to those in peripheral nerve injuries as far as the adult patient is concerned. There is, however one important difference, namely that whereas in peripheral nerve injuries the muscles supplied by unaffected nerves are normal, this is not necessarily the case in the apparently unaffected muscles of a poliomyelitic limb. In the latter the good muscles may be far from normal and in addition the circulation in the limb is more or less defective. These circumstances should be recognized when considering tendon transplantation, for those transplants which are of value in peripheral nerve injuries do not always give comparable results in poliomyelitis.

While surgical reconstruction in adults may be instituted without delay when maximal recovery is reached, in children consideration must be given to the problems of growth. In general, operations for joint fusion should be postponed at least until puberty Thus will be avoided any major disturbance of bone growth, and fusion is more likely to be sound.

Types of Operation Available

(1) **Capsulotomy, Tenotomy Fasciotomy Muscle-slide.** These procedures for the relief of contracture are less likely to be required if early treatment has been efficient. Relief of extreme flexion contracture of the hip is achieved by dividing the joint capsule anteriorly and detaching from their origins the muscles lying in front of the joint. Contracture of the ilio-tibial band is released by division of the tract above the knee.

Tenotomy of the tendo Achillis is an historic operation in the field of orthopaedics. First performed by Delpech of Monpellier in 1816, it was popularized in Germany by Stromeyer and in England by W J Little, himself a victim of a paralytic club foot. The subcutaneous method of tenotomy has now been largely replaced by an open lengthening of the tendon or of the musculo-tendinous junction, as described by Vulpius. Lengthening of the tendo Achillis is not often necessary as sufficient length can usually be achieved by stretching in plaster Moreover the operation can easily be overdone a calcaneus foot is a much greater disability than a tight calf Tenotomy is also occasionally indicated for relief of paralytic torticollis due to a contracted sterno-mastoid muscle.

(2) **Tenodesis, Bone-block.** The purpose of these operations is to provide a passive limitation of the range of movement at a joint. Bruce Gill's operation for genu recurvatum consists of the strengthening of the posterior structures of the knee joint by a check ligament fashioned out of the fascia lata. Hyper-extension is thereby limited. For a drop-foot, Campbell has described a method of restricting plantar flexion by packing chips of bone behind the lower end of the tibia in front of the tendo Achillis. When incorporated, the bone-block limits foot-drop but does not restrict passive dorsi-flexion

such as occurs at the ankle when the foot is on the ground. A tenodesis between the tendo Achillis and the tibia for a paralysed calf muscle has the opposite effect both procedures are often combined with a tarsal arthrodesis

In the hand, the technique of tenodesis may be applied so as to simulate active tendon function. If paralysis of the long extensor tendons of the fingers is associated with strong power of flexion at the wrist, extensor tenodesis will cause the digits automatically to extend as the wrist is flexed.

(3) **Muscle and Tendon Transplant.** The special problem of tendon transplantation in poliomyelitis has already been mentioned. The muscles available for transplant are usually not of normal strength, and the degree of success in any procedure is often proportional to the relative strengths of the donor muscle and that which it is attempting to replace. Established technique owes much to the work of Leo Mayer and Biesalski The transplanted tendon should lie in a good bed it should have a straight pull, and it should be sutured to bone under correct tension. The best results are obtained when synergic muscles are used The latter may be given greater effectiveness in replacing paralysed muscles by transposition in such a way as to increase their leverage without affecting their direction of action Of this an excellent example is provided by Steindler s fore-arm flexor muscle transplant at the elbow The restoration of muscle power by the use of antagonist muscles for transplantation is less successful When it is performed, it is almost always necessary to eliminate by arthrodesis the movement of the joint which the antagonist is designed to control. While no transplant can effectively replace a weakened quadriceps, the biceps femoris transposed to the patella can provide a valuable stabilizing influence in the terminal degrees of extension when the foot is on the ground

(4) **Osteotomy** Osteotomy is an operation mainly for the correction of deformity In poliomyelitis it is applied particularly to the rotational deformity brought about by the disordered action of muscles on bone growth torsion of the tibia is an example in the lower limb In the upper limb, a rotational deformity of the radius, caused by prolonged supination contracture, may be corrected by multiple saw-cut osteotomies. For para lytic dislocation of the hip however sub-trochanteric osteotomy correcting the valgus of the femoral neck, also achieves a stable reduction

(5) **Arthrodesis.** Arthrodesis stabilizes a joint in the optimal position by bone fusion. At the same time deformity can be corrected and associated tendon transplants may improve muscle balance In the upper limb the stabilizing operation of arthrodesis is used for the extension of leverage, so that the elimination of movement in a joint causes muscles to have an effective control on a longer lever Fusion of the shoulder thus per mits the elevators of the shoulder girdle to abduct the arm. In this way the synergists of paralysed muscles are brought into effective use without transposition.

In the lower limb where the main problem is to balance the body weight upon its base of support in standing and walking, arthrodesis has been the principal means of achieving the necessary stability The physiological principle of peripheral fixation is nowhere better seen than in the lower extremity during walking when muscles function more effectively from their insertions as fixed points. Realization of this will explain why muscle transplantations in the lower limbs are so disappointing in their results. It is not difficult to convert the peroneal muscles into dorsi flexors of the foot, but it is indeed difficult for these muscles to control the downward movement of the foot when weight is borne on the heel. Correction of deformity and of lateral instability in the

[illegible] joint is easy by subtalar arthrodesis, and the operation described first by Davis in 1908 is the basis of all other stabilizing procedures. From this [illegible] need of controlling lateral movement of the tarsus, there are some other ideas of [illegible] or stability of the foot itself and of the limb as a whole.

The problem of paralytic calcaneus and its treatment by [illegible] is discussed elsewhere.

In considering the value of the surgery in poliomyelitis it is of real importance to consider not only the part affected but its relation to the remainder of the limb and to the body as a whole. The particular disability in question must be related to sitting, standing, and walking on the level and on gradients. The patient who relies on a [illegible] which stabilises the knee in extension will not thank the surgeon who corrects the deformity in the foot and thereby causes the knee to give way.

Details of Operation

No attempt will be made to [illegible] the large number of procedures which have been devised to deal with the varied situations arising in patients crippled by the effects of poliomyelitis. With [illegible] standards of treatment in the early stages, many operations devised for the treatment of severe deformity are seldom needed. The operations to be described have been successfully tested by the test of time and are established as reliable methods. Occasional reference will be made to certain classical procedures which have now been largely superseded.

(1) The Upper Limb. In planning the surgery of the upper limb it is wise to start distally. Operations on the shoulder and elbow are ineffective unless the hand is useful. In particular, arthrodesis of the shoulder must be left until last, both for the comfort of the patient and for the ease of the surgeon, whose difficulties are considerable if he attempts to operate on the elbow when the shoulder is ankylosed.

In the hand, paralysis most frequently affects the thenar eminence with consequent loss of opposition. Restoration of the pinch movement between the thumb and the other fingers is of prime importance. There are many methods but the one recommended is Phelps's operation as modified by Campbell Thompson, which makes use of the synergic action of finger flexion with thumb opposition. The flexor sublimis tendon to the ring finger is detached from its insertion through a transverse incision at the base of the finger, and it is withdrawn through a palmar incision at the lower border of the transverse retinaculum. A third incision is made on the dorsum of the thumb over the extensor pollicis longus tendon and a subcutaneous tunnel fashioned across the thenar eminence, through which the tendon is pulled. The insertion of the palmaris longus and the palmar fascia then acts as a pulley. A hole is drilled through the neck of the metacarpal and one half of the transplanted tendon is drawn through it; the other half is wound round the radial side of the metacarpal and passed down through a small fascial tunnel at the base of the proximal phalanx. The two ends of the tendon are tightened to hold the thumb in full opposition and are sutured to each other.

In a disabled hand with little power in the flexor tendons, it is better to fix the thumb metacarpal in the opposed position by insertion of a bone block at the apex of the triangle between the first and second metacarpals. Dividing the radial artery in the proximal angle gives good bony contact for the graft throughout its extent. (Some place the graft more distally between the necks of the metacarpals.)

Power of extension of the wrist [illegible] flexion of

Accordingly the Robert Jones transplant, as used for radial palsy is applicable for extensor loss if adequate wrist flexors are available, the tendons of flexor carpi radialis and ulnaris being used as transplants for the extensors of the fingers and thumb and pronator teres for the extensors of the wrist. The exact procedure chosen will depend upon the degree of muscle imbalance in any particular case, but in general it is better to perform tendon transplants before considering arthrodesis of the wrist, for even if the transplanted muscles are not fully effective as active extensors they may by a "tenodesis effect" cause finger extension when the wrist joint is flexed. All wrist flexors should be transplanted only when there is a good palmaris longus. After all transplant operations in the hand, continuous splintage is required for three weeks and thereafter intermittently for the period of retraining by physiotherapy

Arthrodesis of the wrist may be essential to stability While fixation is not needed in order to free the wrist flexors for transplant, it may be required as a preliminary to releasing the extensor tendons for action on the digits. The operation is best performed from the dorsal surface the tendons are retracted and the joint exposed. Cartilage is removed from the lower end of the radius and from the scaphoid and lunate bones. A graft is then cut from the lower end of the radius, turned round and the distal end embedded in the carpus, bridging the joint-space The wrist is immobilized in plaster until union is sound.

Flexion of the elbow may be improved in two ways. The ingenious method described by Clark makes use of the pectoralis major muscle and is most satisfactory when there is a little power in the biceps. The lower portion of the pectoralis major which has a separate nerve supply is separated from the rest of the muscle and detached from its costal origin. It is rotated and given an insertion into the biceps muscle as low down as possible in the arm.

A long established procedure at the elbow is the muscle-slide operation of Steindler This converts the flexor muscles of the wrist and fingers into more affective flexors of the elbow Their common origin is detached and separated downwards for about two inches, care being taken to avoid damage to the nerve supply which enters from below The median nerve must also be avoided as it passes between the two heads of pronator teres. The muscles are then given a new attachment to the humerus about two inches above the medial epicondyle with the elbow supported in mid-flexion.

Muscle and tendon transplants designed to replace a paralysed deltoid have not proved successful. The only procedure worth considering at the shoulder is arthrodesis. As already mentioned, it should be the last stage in reconstruction of the upper limb, and strong power in the trapezius and other rotator muscles of the scapula are essential for success. Arthrodesis gives a reasonable degree of controlled abduction and allows for a strong grip between the upper arm and the chest wall, but the normal contour of the shoulder is altered and free mobility is, of course, lost. Before operation is decided, the patient should be acquainted with these facts.

An incision passing across the shoulder and down the arm, with detachment of the deltoid from its origin, gives a good exposure. The capsule is divided in order to dislocate the shoulder and the cartilage is removed from the humeral head and from the glenoid together with the labrum glenoidale. After obtaining congruity of the surfaces, internal fixation is secured with a trifin nail. A flap of acromion turned down on to the tuberosity of the humerus gives further fixation.

immobilized in a plaster spica until union is sound. In choosing the position for arthrodesis, care must be taken to avoid too great an angle of abduction about 30° is now considered to be sufficient. If more than this is attempted, troubles from aching in the neck and shoulder girdle may occur when the arm is brought to the side, and in children scoliosis may be aggravated.

For the completely flail upper limb a programme of surgical reconstruction has recently been advocated by Hendry The essential procedure is a tenodesis between the flexor and extensor tendons of the digits, which are passed through a gouge hole in the radius just above the wrist and fixed in that position. The thumb is kept in forward abduction by a bone-block between the first and second metacarpals. These operations are usually followed by a posterior bone-block at the elbow to limit passive extension and by arthrodesis of the shoulder By leaning one way or the other and thereby making use of gravity passive pronation or supination of the fore arm may be achieved. When the wrist falls into full supination it automatically drops into extension and thereby the fingers flex and may be used for gripping and carrying. Conversely when the forearm is pronated, the wrist flexes and the fingers automatically extend. Recognizing that in poliomyelitis sensation is not lost, reconstruction of a flail limb may have greater advantages than amputation and a prosthesis.

2. **The Lower Limb.** No method of muscle transplant aimed at reducing instability due to paralysis of the muscles of the hip has proved satisfactory Moreover arthrodesis of the hip joint in poliomyelitis is rarely necessary Instability in the lower limb is generally concerned with more distal joints and paresis of the hip is seldom an isolated phenomenon. Paralytic dislocation however is a lesion deserving special attention Earlier methods of treatment using the shelf operation took inadequate account of the pathology which consists of abductor muscular weakness resulting in valgus deformity of the femoral neck dislocation thus usually occurs in childhood. Stability is achieved by a wedge shaped sub-trochanteric osteotomy so as to produce a relative varus position of the neck. The technique which has been reported by Blundell Jones makes use of a nail-plate to secure fixation at the desired angle. The improved leverage thus made gives better power for any remaining abductor muscle, and further functional recovery may occur once the stability of the hip is assured.

At the knee, arthrodesis is seldom advisable. Weakness of the quadriceps femoris muscle may be lessened by transposition of the biceps as previously mentioned The essentials of technique are adequate preparation of the patellar bed into which the tendon is to be inserted, sufficient upward freeing of the muscle to ensure the best alignment and directness of pull, and firm suture of the tendon with the knee and hip in full extension. In the after-care, the patient should be able to extend the knee against gravity before flexion exercises are begun.

Stabilization of the paralytic foot provides the real basis for reconstruction of the lower limb In order to appreciate the standard procedures of today it is necessary to consider some of the operations which preceded them The first operation designed to stabilize the paralytic foot and described by Davis in 1890 was a sub-taloid arthrodesis. Shortly afterwards, Royal Whitman developed the operation of astragalectomy for the calcaneo-cavus foot. The objects of this procedure were to correct deformity and to increase the leverage of the heel by displacing the foot backwards so that the navicular articulated in the tibio-fibular mortise. In England the operation was popularized by

Laming Evans, who extended it to include other deformities of the foot The operation still has a small place in severe calcaneo-valgus deformities, but it has been displaced by other methods which add stability to the virtues of correcting deformity and improving muscle balance. Astragalectomy has the further disadvantage of increasing shortening in the limb

Based on the two procedures of sub-taloid arthrodesis and astragalectomy Ryerson and Hoke in the U.S.A and Naughton Dunn in England developed the operation of triple arthrodesis, and today this operation in one of its forms is the basic procedure for stabilizing the paralytic foot. Triple arthrodesis implies arthrodesis of the talo-calcaneal, talo-navicular and calcaneo-cuboid joints, and it corrects bony deformity and achieves stability in one operation In addition, the posterior displacement of the foot beneath the talus and the bones of the leg lengthens the heel lever and thereby improves the muscle balance In Dunn s operation, a curved incision is made extending from one inch above and behind the external malleolus to half an inch below this prominence, and then forwards to the base of the third metatarsal. The incision is carried down to bone before the soft tissues are reflected, and the origin of the extensor digitorum brevis is then stripped from the dorsal surface of the calcaneum. The peroneal tendons are divided. Separate reflection of skin flaps is a serious error which may lead to necrosis The strong tarsal ligaments are divided and the foot is dislocated inwards at the sub-taloid and mid-tarsal joints. By the means of an osteotome a portion of bone, including the articular surfaces of the calcaneum and the cuboid, is removed. The head of the talus is divided and the navicular is excised together with the cartilage from the adjacent surface of the cuneiform bones. The amount of bone removed will vary with the deformity to be corrected, and will determine the actual shortening of the foot after the operation The fore-foot and the heel are then displaced backwards on the talus, and a close fit obtained. The peroneal tendons are sutured and the wound is closed. A long leg, padded plaster is applied, care being taken that the heel and fore foot are in the neutral position, and that the plaster is well moulded to restore the normal metatarsal arch and to align both the first and fifth metatarsal heads for future weight-bearing.

Two weeks after operation the sutures are removed and the plaster changed. This change should be performed by the surgeon responsible for the operation. A short anæsthetic is often desirable. A slight valgus position of the foot is acceptable, but any tendency to varus must be corrected at this stage. Plaster splintage is continued until union is sound. The Hoke operation differs from the procedure just described, [illegible] the fact that the navicular is retained and a variable amount of the head of the [illegible] removed. In either case there is actual shortening of the foot as well as reduction of the fore foot lever

This basic operation of triple arthrodesis may be adapted to suit any of the disturbances met with in the paralytic foot. In the presence of minor contracture of the calf [illegible] a coincident lengthening of the tendo Achillis is not necessary while more [illegible] traction should be overcome by slow stretching previously In the cavus foot a [illegible] of the short plantar muscles and fascia from the calcaneum may be performed, as [illegible] by Steindler

Muscle balance may be improved by an associated transplant of the tibialis [illegible] tendon to the outer side of the foot, or less effectively transposition of the [illegible] the inner side

A weak calf musculature is strengthened by the addition of the tendons of tibialis posterior and the peronei, although their combined power does not approach that of the normal calf Peabody has described a method of transposing the tibialis anterior tendon into the heel by detaching it from its insertion, freeing the muscle over the greater part of its length, and re routing it through an opening in the inter-osseous membrane. This operation is of particular value in the young child with an increasing calcaneus deformity

The particular problem of the paralytic equinus foot in a limb with good calf muscles may be treated by Campbell's posterior bone block operation, to which reference has already been made. More reliable is Lambrinudi's procedure, with which is associated a triple arthrodesis With the talus in full plantar flexion, an oblique wedge is taken from its under surface, involving the whole depth of the head anteriorly The lower portion of the navicular is removed and the fore-foot and heel are brought upwards on the talus so that the remaining half of the navicular fits in front of its neck. If necessary the excised bone may be wedged between the posterior portion of the body of the talus and the calcaneum. By this means, the talus locks in the tibio-fibular mortise at an earlier stage of plantar flexion, the further range of which is thereby limited, while at the same time stability of the sub-taloid joint is achieved.

For a flail foot, Steindler devised a pantalar arthrodesis, fusing the ankle joint as well as the tarsus. The particular indication for this operation is to be found in adults with a relatively strong hip and a weak knee. The foot may then be fixed in moderate equinus, a position which will encourage stability of the knee by forcing it into extension when weight is transferred from the toes to the heel This advantage in adults constitutes a danger in children, where a genu recurvatum might develop through such a mechanical effect.

Pes cavus with clawing of the toes is caused by paralysis of the intrinsic muscles of the foot It is comparable to the *main en griffe* of ulnar and median palsy in the hand. Callosities develop over the proximal interphalangeal joints and the heads of the metatarsals. Arthrodesis of the interphalangeal joints of the toes, as advocated by Lam brinudi restores effective action in the long flexor muscles and compensatory elevation of the metatarsal heads. The method is best applied to adolescents, but also can be used for adults in whom there is no actual dislocation at the metatarso-phalangeal joints. Through multiple transverse incisions, each interphalangeal joint is excised the toes are fastened to the sole-plate of a special sandal by means of sutures passed round the proximal phalanges and emerging through the skin of the plantar surface just beyond the web. Immobilization is continued for six weeks, when the sutures are removed and active exercises started. An alternative method of fixation is by intramedullary Kirschner wire.

A special deformity results from isolated paralysis of the tibialis anterior talipes valgus with clawing of the great toe due to unbalanced action of the long extensor The latter is corrected by arthrodesis of the interphalangeal joint and transposition of the tendon to the metatarsal neck.

(3) **The Trunk.** The serious deformity of fixed pelvic tilting is an uncommon sequel to adductor paralysis of the hip or to an uncompensated short leg. It may be the cause of a structural scoliosis or one of its effects, and a number of operations for its relief have been devised by Mayer on the earlier work of Lowman.

The problem of paralytic scoliosis is discussed elsewhere.

Growth Disparity in the Lower Limb. In adults, shortening up to ¾ in may be ignored and up to 1½ in. may be conveniently countered by a raise on the shoe. At the other extreme, shortening of 6 in. or more, associated with flail foot and faulty circulation may best be treated by amputation and the fitting of a prosthesis The patient in whom the disparity in length falls between these two extremes must choose between wearing a high boot and undergoing operative treatment. A raise on the shoe should be made of cork for the sake of lightness for men, the appearance of shortening may be partly concealed by wearing an O Connor extension, in which a form of double boot is provided, the inner leather work holding the foot in marked equinus.

The operative methods available differ for adults and children, but each has its own indications and dangers. The decision to operate requires mature judgement and a frank discussion with the patient or parents. Leg-equalization in adults may be brought about by lengthening the affected limb or by shortening the normal one. Lengthening is the more dangerous procedure, but Allan (1951) considers it to be the operation of choice in a limb with good nutrition and muscle control. Abbot (1927) established the fundamentals of the technique of oblique osteotomy of the femur or tibia and fibula. Care is taken to disturb the soft tissues as little as possible Two Kirschner wires are inserted above and two below the osteotomy and distraction is started immediately proceeding at the rate of about $\frac{1}{16}$ in a day It is subsequently regulated by the patient s reaction. Watch is kept for lateral popliteal paresis, vascular disturbances and for the development of skin pressure. Radiographs are taken at intervals, and when the required length has been obtained the limb is left undisturbed on the apparatus until there is sufficient new bone to support the osteotomy The main dangers arise from over stretching of the neuro-vascular bundles or from delayed union of the osteotomy but efficient after-care should leave no permanent ill-effects for gains in length in both tibia and femur up to 2 in. In Allan s series, the greatest gains were 3½ in in the femur and 4½ in. in the tibia.

Leg shortening is an easier procedure but it has the disadvantages of surgery on the normal leg and of leading to a loss in height. The two methods recommended are, (*a*) an oblique osteotomy of the femoral shaft and lateral over-lap with transfixing screws and (*b*) excision of a segment below the lesser trochanter and fixation with an angled nail plate. These procedures are not fraught with any particular complications and shortening up to 4 in. may be obtained if needed.

Leg equalization in the child can be accomplished by arresting growth of the epi physes. Epiphysiodesis is a procedure introduced by Phemister (1933) and is of established value Blount s method of mechanical retardation of metaphyseal growth by staples is still in an experimental stage. The operation of epiphysiodesis involves the removal of blocks of bone from both sides of the epiphyses of the lower end of the femur and the upper end of the tibia. Through the exposure thus gained the greater part of the epiphyseal cartilage is removed. The bone blocks are then replaced the other way up, i.e. the cartilage-containing portion directed towards the diaphysis. In order to deter mine when to operate, the bone-age of the patient is estimated by radiographs of the wrists and comparison of the films with a standard such as that prepared by Todd. On the basis of the child's height and skeletal age the anticipated growth discrepancy can be predicted and the right time chosen for epiphysiodesis.

The whole problem of growth disparity is influenced by philosophical considerations,

Is it better to predetermine a child's adult stature by operative intervention and risk psychological complications as a result or to permit the continued use of surgical appliances of which an adolescent may become over-conscious?

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CHAPTER XIX

ORTHOPÆDIC SURGERY IN SPASTIC CONDITIONS

O J VAUGHAN-JACKSON

CEREBRAL PALSY

CEREBRAL palsy is the name given to a group of conditions in which neuro-muscular co-ordination is thrown out of gear by lesions of the brain, and though such catastrophes can clearly occur at any age the term cerebral palsy is usually confined to cases which are congenital or occur in early childhood.

In 1841 W J Little, later senior physician of The London Hospital described in the *Lancet* a condition of spastic rigidity in the limbs of new born children. Twenty years later he read to the Obstetrical Society a paper "on the influence of abnormal parturition, difficult labour premature birth and asphyxia neonatorum on the child, especially in relation to deformities," based on 200 cases. This was a classic and his description, so full and so accurate, has stood the test of time till today

The ætiology of the group of palsies is by no means clearly understood yet. Little himself despite the title of his paper laid more stress on "interruption of the proper placental relation of the fœtus to its mother and the non substitution of pulmonary respiration" than on direct mechanical injury to the brain and spinal cord. While it is tempting to relate cerebral palsies directly to a relatively high incidence of difficult, complicated or precipitate deliveries in these cases, it is the frequency of cyanosis, delayed respiration, convulsions, and lack of animation in these infants when new born that is the real pointer Direct mechanical damage is usually localized and results in hemiplegias.

Apart from placental or pulmonary respiratory factors, intra uterine degenerative and toxic factors, as well as primary cerebral aplasias, account for an important group Cerebral changes varying from microscopic developmental changes up to gross developmental abnormalities are found as well as primary neurone degeneration resulting in lobar atrophy and sclerosis

Another undoubted cause is Rhesus incompatibility though the rarity of second cases in affected families is curious.

Rarely post natal causes produce a cerebral palsy—thromboses due to specific toxins (measles, whooping cough encephalitis), tumours, syphilis, have all been blameworthy

The Types of Cerebral Palsy

These vary according to the situation of the major lesion. From the ætiology it is only to be expected that cases should be frequently of mixed type, since the cerebral lesions are scattered.

The mixture comprises

(1) Spasticity—due to motor cortical lesions.

(2) Athetosis—due to lesions of the basal ganglia and corpus striatum.

(3) Ataxia—due to presumed cerebellar lesions.

(4) Rigidity, Tremors, Atony —a small group—aetiology uncertain.

(5) Sensory defect—visual, auditory and kinaesthetic rather than tactile.

(6) Mental defect.

Some 66 per cent of cases seem to fall in the spastic group—athetoids 20 per cent, ataxics 8 per cent, the remainder comprising cases of rigidity and tremor and mixed cases.

Spastic Palsy The terminology of this condition is imprecise. The term paraplegia is sometimes used somewhat differently from paraplegia due to, say spinal injury Diplegia is used to describe a tetraplegia with legs more affected than arms while the reverse (arms worse than legs), has been called a double hemiplegia. It seems more rational to follow Brockway (1936) and refer to

Monoplegia—one limb affected	Rare
Hemiplegia—arm and leg, same side	32 per cent
Diplegia—both arms, or both legs	28 per cent
Triplegia—three limbs	Rare
Quadriplegia—four limbs (or better tetraplegia).	28 per cent

In these cases we are dealing basically with an enhancement of the stretch reflex due to the cutting off of higher inhibitory control. While the child may be capable of relaxing, voluntarily or while asleep the least stimulus, whether it be weight bearing or merely the attempt to move, will set off the enhanced reflexes. An unrelenting type of contraction of the affected muscle groups is set up. It is rarely balanced and the resulting posture reflects the preponderance of this group or that. There is no set picture of abnormal posture though there is a common type In this we see the feet in equinus and varus with knees and hips flexed, the femora adducted and internally rotated until the legs, frequently cross each other in the scissor position. In the upper limb the common posture is of some abduction and internal rotation at the shoulder flexion of the elbow pronation of the forearm, palmar flexion of the wrist, adduction of the thumb into the palm, flexion of the metacarpophalangeal joints and hyperextension of the interphalangeal joints.

The unrelenting pull of unbalanced spastic muscles will always produce progressive deformity if it is not mastered but as well as this in terms of function it means stiffness, jerkiness and clumsiness of all movements. Methodical examination will show that not all muscle groups are spastic. Some muscles, often the opponents of spastic ones, may be quite flaccid (Fairbank 1926). Whereas it used to be thought that spasticity was due to a pure upper motor neurone (Pyramidal) lesion it is now believed that lesions of the immediate pre-central cortex (Brodman area 4) produce a flaccid paralysis and that it is lesions of the suppressor strip (Brodman area 4S) that produce spasticity (Dusser de Barenne, 1941). It is thought that destruction of area 4S eliminates its suppressor effect on pyramidal impulses, and on those controlling tone and posture which originate in the basal ganglia and travel via the extra pyramidal tracts to facilitate the stretch reflex, and other postural reflexes, thereby producing enhanced peripheral reflexes and spasticity

A widespread lesion may encroach on the frontal lobes and produce associated mental and sensory defects.

Athetosis. This condition, in its severer forms, is the most disabling of all In such a case we are confronted with an apparent idiot dribbling, grimacing and writhing. Speech is often grossly affected sensory defects especially of hearing are common and these in turn tend to make attempted speech even more unintelligible. The writhing movements of the limbs, and the grimacings, are not continuous but wax and wane, especially under the influence of excitement or emotion. Yet despite all appearances to the contrary many of these apparent idiots are highly intelligent—which only heightens the tragedy of their condition.

Two types are described (though not all neurologists are agreed upon this).

(1) *Athetosis without tension*—which is simply the condition as just described above

(2) *Athetosis with tension* thought to be due to *a conscious effort, by voluntary* muscular contraction, to control the involuntary movements, which with time becomes unconscious and continuous, so that an appearance of spasticity is produced. But it is a so-called "lead pipe" rigidity not the "clasp-knife" rigidity of the true spastic.

The cerebral lesion in athetosis is in the corpus striatum and results in a continuous discharge of abnormal motor impulses down the extra pyramidal tracts, instead of the normal controlling and co-ordinating impulses.

Ataxia and Rigidity Are both thought to derive from cerebellar lesions. The latter is of the "lead-pipe" type. Section of the posterior spinal roots does not affect it so that it is regarded as due to a continuous primary motor discharge instead of an enhanced stretch reflex.

Treatment. The treatment of these conditions is a matter of specialized team work under specialized conditions. First the pædiatrician and the neurologist have the difficult task of *assessing* the case diagnostically and not of merely attaching a diagnostic label to it. The psychologist too has an important part to play in diagnostic assessment of the child but his role is difficult and beset with uncertainties. The psychology of a child is hard enough to keep up with, changing as it does from day to day but to assess the changing mentality of an abnormal child with severe defects of communication is extremely difficult and the impression is inescapable that sporadic or infrequent psychological assessments, though necessary and excellent at times, are quite often less reliable than the rather "home-spun" estimate by the nurse or house-mother and at times can be seriously misleading. The thing one soon learns with these children is NEVER to make a final assessment of any of them, either physically or psychologically One must be constantly alert against underestimating them.

Once diagnosed the child needs constant help Treatment, under guidance, in the home may be suitable for the mildest cases, or for those palpably beyond help but for the remainder those capable of improvement, great or small, there is really no satisfactory answer but the school for the physically handicapped. *Generally if the child is* to get sufficient individual attention a residential school is necessary but a growing number of day schools of this type are beginning to prove their worth. But a team of teachers, physiotherapists, speech therapists, occupational therapists, nurses, house-mothers and doctors must, with a high degree of dedication to their task, set about the business of making the child feel at home, among friends, secure, content and interested enough in *what can be nothing but a* long and uphill struggle.

The basic attack upon all these palsies is by way of specialized forms of physiotherapy There is no unanimity on methods which is perhaps not surprising considering the protean manifestations of the disease In cases of athetosis the first aim is the achievement of relaxation Upon this is then slowly built a pattern of simple movements achieved, and repeated, and gradually progressing to more complex efforts, but throughout returning, after each effort, to the basic necessity for suppression, by relaxation, of the involuntary movements. Nothing calls for greater patience than this and in all but the mildest cases not much more than an ability to look after itself and take a limited part in social activities is conferred upon the child. Orthopædic surgery has little or no part to play since the abnormal postures and contractions are not sustained, but change constantly and therefore do not commonly produce deformity Neuro-surgical approaches perhaps offer the greater hope. The localized intracerebral injection of alcohol by which a "chemo-pallidectomy" is carried out is a procedure which by its very nature is unpredictable and hard to control, and radiographic studies of the wanderings of injected radio-opaque fluids make one view the method with some alarm. Be that as it may the startling improvement that has been achieved in some cases gives food for serious thought and may provide the key to more precise and safer methods.

In spastic cerebral palsy the outlook is better and the methods more varied. This is the palsy that produces deformities and throughout a child's treatment we must be constantly ready to apply standard orthopædic methods (to which the latter part of this contribution is devoted) while realizing that they are but incidents in a far wider ranging and continuous scheme of motor training. Over the methods of this training controversy rages, schools of thought grow up reputations are staked, made and lost and, regrettably vituperation is apt to break out. The orthopædic surgeon is not infrequently attacked, sometimes, one fears, simply because his interventions are surgical in what is regarded as a strictly medical field His standpoint, *vis à vis* such attackers, is really unassailable it is that the primary attack on this disability *must* be conservative, non-surgical and re-educative, according to whichever school of thought appeals most, but that where such methods fail to achieve improvement, or do so excessively slowly to continue to employ them, to the exclusion of surgical assistance, is merely to preside over the development and establishment of deformity which is indefensible Making every allowance for the extremely difficult surgical judgements which must precede surgical interventions, they must be considered and permitted when other methods fail Their aim is to permit the *resumption* of effective retraining by getting the patient over a hurdle They should be part of a scheme of treatment and should not be looked upon as a rival method

In this country conservative treatment is coming more and more to be compounded of the best features from several methods. For details of these the reader must be referred to more specialized sources. Here we may briefly mention first Winthrop Phelps of Baltimore He has advocated the development of movement patterns, firstly repetitive passive movements, then assisted active movements, then unassisted, and finally carried out against resistance. This is directed towards building up the strength of normal or weak muscles while diminishing the preponderance of the spastic ones—to which latter end stretching, bracing and splinting are also used.

Next Carlson emphasizes the educational approach in so far as providing the child with some form of self expression—speech, writing, typing, or drawing—is a *sine qua non* if his co-operation is to be gained in the painfully slow process of motor re-education.

Temple Fay lays stress upon the importance of the primitive amphibian patterns of movement residing in the mid brain and cord as being utilizable for the development of new motor patterns when the normal initiating impulses from the motor cortex are defective or cut off The Bobaths rely mainly upon the inhibition of abnormal reflex activity by enforced postures. For example a cerebral palsied child will sit with a round back, the head falls forward and the arms are bent and held close to the body He will lie with the head thrown back and the legs adducted or crossed. The "reflex inhibiting posture" is broadly in each case, the opposite posture and the manipulations advocated are, broadly those which insist, repetitively on the assumption of this opposite posture until reflex opposition to it is overcome.

None of these concepts is all embracing, nor do the theories behind them command complete acceptance. But there can be no question that each has made a very real contribution to the practical side of training these unfortunate children.

Returning to surgical methods in spastic cerebral palsy *first* it must be faced that in about half of these patients nothing can be done because of too grave motor or mental defect, or continuing impairment of balance.

Second, a surgical procedure is not an end in itself It is an attempt to get the individual over an obstacle which has halted his re-education. Training must be resumed intensively as soon as possible after operation.

Third, a painstaking analysis of the motor defect is essential. There are many pitfalls.

Fourth the outlook for surgery in the lower limb is reasonably good in the upper it is poor

METHODS

(1) Manipulations

Stretching, under anæsthesia, of joint deformities such as equinovarus of the foot, flexed knees, or flexed adducted hips, followed by immobilization in plaster in the corrected position is often effective and a subsequent spring back to the deformed position is by no means inevitable. The plaster must be kept on for several weeks to achieve a permanent improvement, but after a few weeks removable splints enable us to resume muscular training earlier than otherwise. Night splints may be continued for very much longer indeed indefinitely

(2) Braces

In obstinate cases braces such as below knee irons or callipers with locking knee hinges may be necessary for a while longer What should not be forgotten, but often is, is that the aim is to free an already handicapped individual from hindrances. If the deformity is going to require heavy appliances permanently we must consider seriously whether a grotesque but nimbler gait is not a better bargain for the patient, or whether some surgical procedure cannot rid him of encumbrances.

(3) Operations on the Nervous System

(*a*) ON THE BRAIN. Brain operations have little to offer The damage has been done and removal of a "lesion" will not *restore* function. Cerebral operations for complications such as epilepsy are in a different category

(*b*) On the Spinal Cord Tractotomies or rhizotomies are virtually never performed in spastic cerebral palsy in contradistinction from the spasticity of multiple sclerosis. Painful spasms are not a feature of cerebral palsy and intractable contractures are dealt with along other lines.

(*c*) On the Sympathetic System. Section of sympathetic roots has been tried (Royle) but abandoned as useless.

(*d*) On Peripheral Nerves. The work of Stoeffel was directed towards reducing the preponderance of spastic muscles by paralysing them wholly or in part by an attack upon their motor nerves. In his original technique a fasciculus of the nerve trunk, destined to become a motor branch to a particular muscle, was identified by suitable gentle faradic stimulation with a needle electrode, dissected free, and divided. It is as satisfactory and simpler to divide the motor branch itself somewhere close to the muscle concerned.

The method may be employed for equinus deformities, when the nerves to gastrocnemius or soleus are divided according to which muscle is preponderantly spastic. It is also used on the obturator nerve to reduce an adduction deformity at the hip.

In the arm it has been most commonly used to correct a pronation contracture by dividing the nerve to pronator teres.

It is clear that the procedure is irrevocable, and so it is called for only when more conservative measures have failed. Then it may be justified, but clearly it may be desirable to retain *some* power in the offending muscle, as by shifting its attachments, *when to do a Stoeffel operation would paralyse it. Again it is clear that the procedure* cannot correct a fixed contracture. In such a case part, at least, of the attack must be direct, upon the shortened structures.

(4) *Operations on Muscles, Tendons and Ligaments*

Lower Limb (i) *Foot and Ankle* The commonest indication here is an *intractable* equinus deformity If both soleus and gastrocnemius are short and lengthening of the Achilles tendon itself is called for this will weaken the calf muscles but a trap lies in lengthening too much and thus producing an equally troublesome calcaneus deformity When bone surgery on the foot is contemplated—say a subastragalar-midtarsal arthrodesis—this should precede the tendon lengthening, the intact short tendon providing an essential fixation for the calcanean half of the arthrodesis during healing.

Closed tenotomy of the achilles tendon is undesirable wide retraction of the ends ensues and one has no satisfactory control over the ultimate length of the tendon.

If the equinus is due mainly or wholly to a tight gastrocnemius when it can be wholly or partly corrected if the knee is bent, it is desirable to leave the soleus undisturbed. First we can, through a vertical mid-calf incision, raise the lower end of the gastrocnemius off the soleus fascia (incising the latter too if it is contracted), and allow it to retract proximally (Fig. 350). Second we can, though less simply free the origins of the muscle *from the femoral condyles* and allow them to retract distally

When the equinus is complicated by varus as well, the tibialis posticus is usually the major factor in producing the varus component. Simply to divide it removes the cause but wastes a motor Provided the calf muscles are strong enough a satisfactory procedure is to bring the tibialis posticus tendon *through the interosseous membrane* between the leg bones, and to attach it to the dorsum of the tarsus at, or just external to, the mid-line (Fig. 351). To attach it far out on the cuboid may produce an undesirable valgus

deformity If the calf muscles are inadequate the transposition may result in a calcaneus deformity At the same time too much should not be expected Spastic muscles are apt to produce disappointing function when transferred The important factor is the removal of the deforming force.

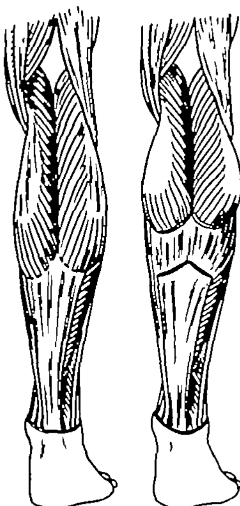


FIG. 350. *Gastrocnemius Recession.* The muscle is lifted off the underlying soleus, divided at its musculo-tendinous junction, and the bellies allowed to retract proximally

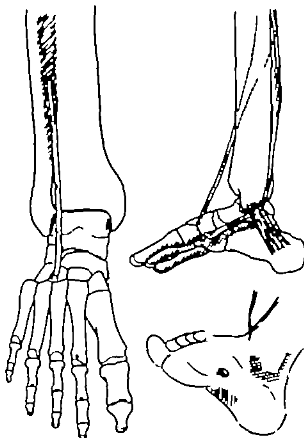


FIG. 351 *Anterior Interosseous transposition of Tibialis Posticus.* The muscle is detached at its insertion into the tubercle of the navicular freed, and its tendon led through an opening made in the interosseous membrane, to be re-attached to the tarsus somewhat external to the mid-line of the foot.

(ii) *Knee* The usual deformity here is a simple flexion deformity though sometimes it is asymmetrical and rotation of the tibia may be introduced by inner or outer ham strings predominating. The spastic contracture results, in the main, in the usual adaptive shortening of ligaments, and fasciæ, which make the contracture fixed, but in the case of the patellar tendon there is an adaptive lengthening. Especially is this so if the quadriceps is in marked spasm if it is not, the lengthening of the extensor apparatus may take

place in its muscular portion. The usual result however is a stretched patellar tendon the patella resting noticeably high up on the anterior surface of the lower end of the femur

Other methods having failed, we can clearly try lengthening the posterior structures or shortening the anterior or in some circumstances, both.

Lengthening the Posterior Structures

The simplest method is simply to tenotomize the hamstrings behind the knee. Posterior capsular contracture may need division before the knee can be extended by

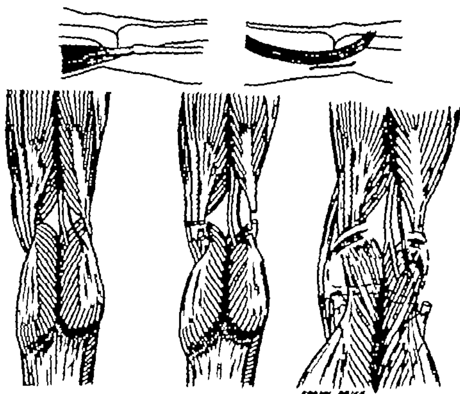


Fig. 352. *Division of Hamstrings with reattachment to lower end of Femur* The inner and outer hamstrings are approached through curved incisions as shown and divided close to their insertions. When the knee is extended their ends retract to lie over the femoral condyles where they are reattached by suturing them in position in shallow bony excavations under raised bridges of periosteum (after *Eggers*)

the now unopposed quadriceps. But such a method is crude and overlooks the fact that the hamstrings bridge two joints they are extensors of the hip as well as knee flexors, and after perhaps years of knee and hip flexion when standing, the patient will need all the hip extensor power available if he is to stand upright when his knees are released. It is better then to reattach the hamstrings to the femoral condyles (Fig. 352) They can then extend the hip without flexing the knee The latter function is maintained by gastrocnemius, popliteus, sartorius (which should not be divided with the ham strings) and tensor fasciæ femoris. We cannot be sure of the extensor power of the

quadriceps until the knee is released and sometimes it will prove insufficient and a stabilizing calliper may be needed permanently

SHORTENING THE ANTERIOR STRUCTURES

Certain factors commonly prevent the quadriceps from exerting its full force. When the knee is released from flexion it may be found that the patellar tendon is stretched out of proportion to the lateral portions of the vasti and fascial quadriceps expansions—the so called patellar retinacula. The latter are mainly attached somewhat laterally on

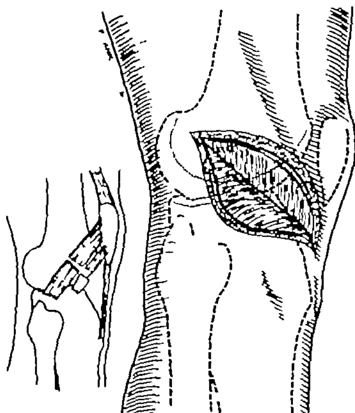


FIG. 353 *Division of Patellar Retinacula.* The outer side only is shown. The expansion is divided, down to the joint capsule, through a curved incision The small diagram indicates how this permits the full strength of the quadriceps to be exerted upon the patellar tendon (after Eggers).

the upper end of the tibia. If they are too short relative to the patellar tendon the main pull of the quadriceps will fall upon them and the effective extensor action on the tibia will be very slight. To correct this we can either divide the retinacula, when all the pull will come on the patellar tendon—or tighten the patellar tendon in some way The choice will depend considerably on the position of the patella. If it is the common "high patella" of spastics, shortening the patellar tendon will obviously be more appropriate If the patella is not unduly high we can more easily divide the patellar retinacula, a simple procedure (Fig. 353), and let the quadriceps pull directly on the patellar tendon.

To shorten the patellar tendon we can raise the block of bone at the tibial tuberosity to which the tendon is attached and shift it bodily distally into a prepared bed fixing it with a screw (Chandler) (Fig. 354). But this interferes with the anterior portion of the upper

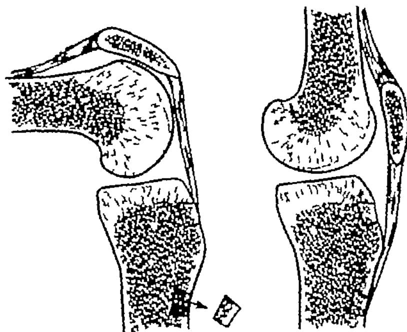


FIG. 354. *Distal Displacement of Insertion of Patellar Tendon.*

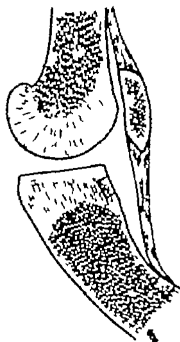


FIG. 355 *Tibial Recurvatum Deformity* caused by interference with the anterior portion of the epiphysis when shifting the patellar tendon attachment

tibial epiphysis and by causing premature fusion at this point may result in a troublesome degree of recurvatum deformity of the tibia (Fig. 355) It is therefore unsuitable in young children. To avoid this Chandler employed another rather complex reefing procedure on the tendon itself holding the patella in its new position by a wire loop passed through it and through the tibia (Fig. 356) This wire has to be removed after eight weeks when the tendon is healed and consolidated.

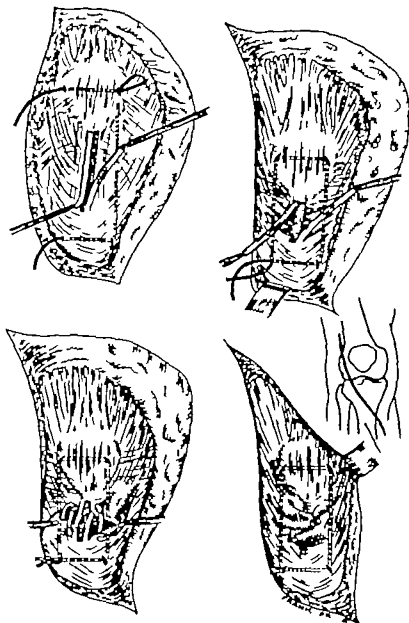


FIG. 356. *Reefing the Patellar Tendon.* The method of reefing is self explanatory The wire passed through the patella and tibial tuberosity is only a temporary method of keeping the patella displaced distally to take tension off the suture line. It is removed after 6–8 weeks (after Chandler).

A simpler method is to divide the tendon itself close to its insertion and bury the distal end under an osteo-periosteal trap door raised on the tibia below the tuberosity Tendon and trap door are fixed with a single screw and the limb held in plaster in extension for six weeks till the tendon is firmly united to bone (Fig. 357). This spares the epiphysis and is suitable for the younger patient.

Knee flexion deformities due to tightness of the tensor fasciæ femoris are more typically seen after poliomyelitis when they are commonly associated with a flexion-abduction deformity at the hip *The same effect, however can be produced by selective* spasticity of the tensor (*see* Hip below).

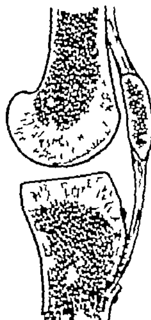


Fig. 357 *Distal reattachment of Patellar Tendon under an osteoperiosteal trap-door*

The transference of overactive hamstrings to reinforce the quadriceps seems a rational procedure but in practice it is disappointing. Nevertheless it can be effective in carefully selected cases. A transfer must be made of both inner and outer hamstrings since transferring, say the biceps alone tends to produce a lateral luxation of the patella and the intact inner hamstrings rotate the tibia unopposed

(iii) *Hip* There are traps for the unwary in diagnosing the nature of the deformity Spasticity of the adductors alone produces only adduction A scissors deformity requires some flexion at the hip as well and hip flexion can be produced in various ways. A tight tensor fasciæ femoris, which spans both knee and hip, will flex both. Its position in a plane lateral to the hip joint makes it an abductor but this action can be overcome by tight adductors if knee and hip are flexed sufficiently *It is not so generally* realized that the gracilis, which is the only adductor which spans both joints, can produce a flexion adduction deformity *To test it, if the child is laid prone with knees flexed and thighs widely abducted, passive extension of the knees will produce adduction of the* thighs if gracilis is tight.

Remembering the patchiness of distribution of spasticity in a limb we must be sure that an adduction deformity is not due to flaccidity of the abductors, when an adductor

tenotomy or neurectomy may correct the deformity but will not produce a stable hip Stability may be only attainable with the femur adducted as far as it will go when a combined rotational and angular supracondylar osteotomy of the femur will allow the legs to pass each other without destroying hip stability

PROCEDURES

(*a*) ON TENSOR FASCIÆ FEMORIS. The origin of this muscle can be detached and replaced more posteriorly (Legg) so that it becomes an abductor and even an extensor of the hip (Fig 358) Barr achieved the same result by freeing its anterior border and turning

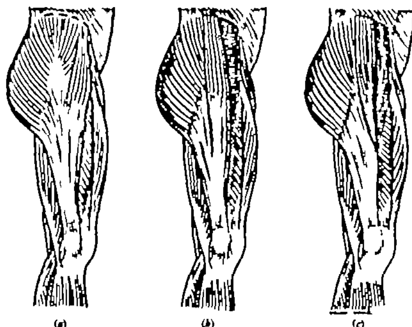


FIG 358. *Posterior reattachment of Origin of Tensor Fasciæ Femoris.* (*a*) Line of detachment. (*b*) Reattachment (Legg). (*c*) Reattachment (Barr).

the muscle back like the page of a book. This method avoids damaging the motor nerve which enters the posterior border of the muscle.

(*b*) ON GRACILIS. Section of this muscle where belly and tendon meet will correct flexion deformity due to its spasticity

(*c*) ON THE ABDUCTORS, INTERNAL ROTATORS AND FLEXORS. In the Soutter procedure the gluteus medius and minimus are detached from the outer face of the ilium and drawn down as the hip is extended (Fig. 359). The tensor can be moved in the same way or the fascia lata can be divided below the muscle belly Subsequently while the limb is immobilized in the corrected position the muscles pick up a new attachment more distally The two components of the operation, on the glutei and on the tensor allow us to vary the procedure according to the relative amounts of flexion or internal rotation in the deformity

The method can be extended if need be to include the origin of sartorius rectus femoris, iliacus (from the inner face of the ilium), together occasionally with a tenotomy of the psoas tendon.

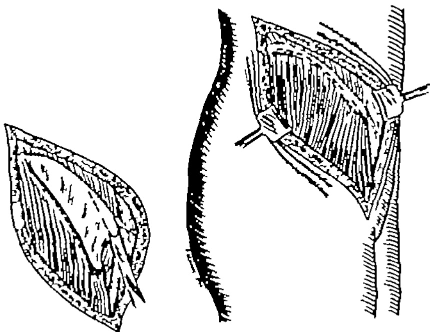


FIG. 359. *Downward stripping of origins of Tensor and Gluteus Medius and Minimus* (Soutter). This leaves the anterior superior iliac spine very prominent under the skin. As much of it as may be necessary can be removed with the osteotome.

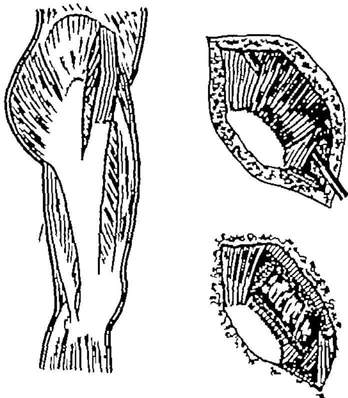


FIG. 360. *Division of Anterior fi* ... *edius and Minim* ...
(Durham) to overcome interna ... y

An alternative method (Durham) is to detach the anterior fibres of gluteus medius and minimus from the trochanter thus cutting out their internal rotator effect (Fig. 360)

Either procedure weakens abductor power at the hip and must be employed with circumspection if stability is to be preserved.

(*d*) ON THE ADDUCTORS. Spasticity or contracture of this powerful group of muscles may be a dominant feature and tenotomy of its origin may be necessary before some of

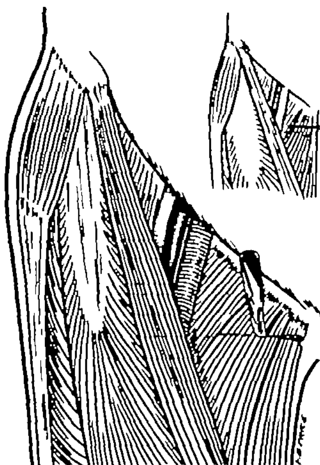


FIG. 361 *Tenotomy of Adductor origin.*

the procedures described above can succeed. Such a tenotomy is a valuable procedure It is simple and can be varied in its extent we can come back to it after trial and tenotomize more of the adductor origin if necessary This is a valuable feature in striking the delicate balance between abnormal muscle groups (Fig. 361).

In all these operations immobilization in plaster in the corrected position for 6–8 weeks is necessary for soft tissue healing and consolidation.

Upper Limb. The motor function of the upper limb is so complex that its disturbance in cerebral palsy is usually also so complex that the relatively simple surgical alterations we can make cause only very slight improvement—if that. The analysis of

the disability that must precede any operation is even more difficult than in the lower limb. No elaborate programme can be planned ahead. Each fresh step has to be carefully thought out when the results of the preceding one are apparent. It must be faced that only in a very few cases will surgery be justified.

In general the disability worsens down the arm from shoulder to fingers and very rarely will any procedure be justified at shoulder or elbow. In cases of severe and hampering internal rotation at the shoulder it may be necessary to divide the internal rotators (pectoralis major and subscapularis) and also, if adduction deformity is severe, the attachments to the coracoid process of coraco-brachialis, pectoralis minor and the short head of biceps.

PROCEDURES

The operations most commonly employed are

(i) *Division of the Pronator Teres* (with or without its transference to extensor carpi radialis longior). This will release the spastic pronation deformity that is such a regular feature in these cases. The re-attachment of the muscle to a wrist extensor may be unnecessary but in any case it is apt to add but little to function. It may however be effective and call in turn for a balancing reinforcement to the ulnar extensor—usually flexor carpi ulnaris is transferred to extensor carpi ulnaris—if radial deviation at the wrist is to be avoided.

An alternative (Steindler) is to detach flexor carpi ulnaris from the pisiform and re-route it across the back of the forearm and reattach it to the lower end of the radius with the object of restoring supination.

In cerebral palsy those procedures which remove a deforming force are much more reliable than those which seek to replace it by a correcting pull, and tendon transfers are commonly disappointing.

(ii) *Procedures for Acute Flexion Deformity at the Wrist.* Often the hand and wrist are in an attitude of flexion with the thumb clasped in the palm, and the fingers unable to be extended. Despite this the patient may from time to time be able to extend the fingers and grip something, but often only with the wrist flexed. It is necessary to test hand function with the wrist held in the neutral position, or somewhat dorsiflexed in plaster if necessary for weeks, as the tight flexion contracture of the fingers which is at first apparent is not necessarily fixed and may gradually relax. If this happens then a wrist flexor to wrist extensor transfer may be appropriate. Usually an arthrodesis of the wrist will be more dependable.

If this flexor relaxation does not occur then the patient will probably do better with the flexed wrist left as it is.

(iii) *Procedures to restore grip and pinch.* The thumb clasped in the palm prevents any effective grip or pinch. Sometimes the mere securing of some ulnar deviation at the wrist, by a splint or an arthrodesis, may bring the thumb out, and into action. To divide abductor pollicis longus, attaching its belly to extensor pollicis brevis and fixing its tendon to the lower end of the radius may keep the thumb metacarpal stable in abduction with some enhanced extensor power on the phalanges (Fig. 362). Usually the carpo-metacarpal joint, being so mobile, has also to be stabilized by an arthrodesis.

Again a bony fusion (in this case between the first and second metacarpals) may be the more dependable form of stabilization (Fig. 362).

The thumb however constitutes only half a grip or pinch and it is in the fingers that we may well meet insuperable difficulties. Allowing, then that we would not have embarked on any programme without some promise of useful finger function, certain procedures are helpful.

In the common persistent hyperextension at the proximal interphalangeal joints we

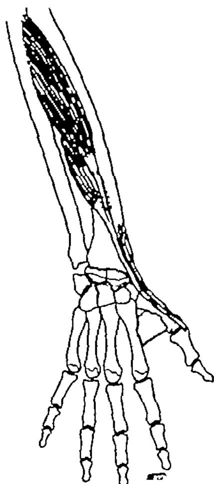


FIG. 362. *Illustrating two methods of securing abduction of the thumb metacarpal* (a) Tenodesis of abductor pollicis longus using its belly to reinforce extensor pollicis brevis. (b) Fixing the thumb metacarpal in abduction by a bone graft between it and the 2nd metacarpal.

may divide the lumbrical attachment to the lateral bands or carry out a Littler release (see section on muscles and tendons)

In the opposite condition of persistent interphalangeal flexion due to weak extensor action we may be able to reinforce the lumbrical action by taking a slip from flexor sublimis digitorum (usually from the ring finger) and re-routing it through the lumbrical canal to insert into the lateral band of the extensor hood.

However these attempts at substitution to achieve control of fine finger movements are commonly defeated by the neuromuscular imperfections and often an arthrodesis of one or more joints is the best we can do Each case is a problem on its own, with many combinations of methods to consider and try—but the odds are heavily against us.

(5) Operations on the Bone

(*a*) Arthrodeses. From what has been said it will be clear that these have their place mainly in the foot and hand. They are hardly ever employed at shoulder elbow hip knee or ankle.

In the foot any of the well recognized methods of stabilization may be appropriate but none will succeed in the presence of the persisting powerful pull of spastic muscles Tibialis posticus the peronei and the calf muscles are the commonest offenders and

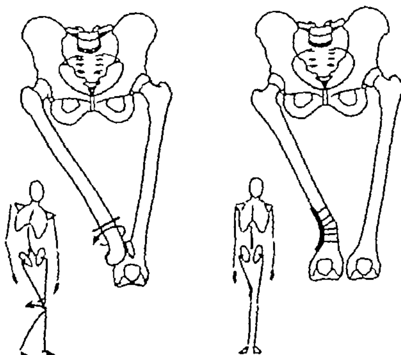


Fig. 363 *Correction of adduction-internal rotation deformity by angular and rotational (supracondylar) osteotomy of the femur* If the hip abductors are flaccid the joint may achieve stability for weight bearing only in the fully adducted position. This osteotomy allows this stability to be utilized without a cross leg deformity ensuing.

lengthening of the tendo achillis or transfers of the peronei and tibialis posticus will often be necessary

In the hand arthrodeses of individual joints are sometimes the only effective means of maintaining a functional position of the greater part of a digit, or indeed of the hand itself while as much as possible of the defective muscle power is concentrated, by training or by surgery in simple movements at the remaining joints.

(*b*) Rotational Osteotomy of the Femur. As already mentioned this may offer the only solution when the flexion and internal rotation deformity at the hip is of long standing and is fixed, or when there is no prospect of the abductors maintaining stability if the deformity is released. It is usually carried out at the supra-condylar level and the lower fragment is abducted and externally rotated until the knee and foot point forward (Fig. 363). It is essential to use a plate and screws to maintain the position against the pull of spastic muscles while healing occurs. For the same reason plaster immobilization

must be maintained till consolidation of union is well advanced or bending, including the plate, may occur at the site of the healing osteotomy

(6) Amputations

Occasionally a case will present itself where amputation of a hand and perhaps a forearm may be an entirely acceptable procedure. Remembering that the disability worsens from shoulder to fingers, a patient with a hemiplegia or a monoplegia affecting one arm, in which the hand is tightly and immovably clenched, may be significantly better off with an artificial hand and arm Commonly movement at the shoulder is sufficiently well controlled for the patient to be able to "wield" a prosthesis and the usefulness of modern artificial arms is very considerable if the patient is sufficiently determined.

Paraplegia, Hemiplegia, and Multiple Sclerosis

In other spastic conditions—paraplegia or hemiplegia from any cause, or in the patchwork of neuro-muscular disorder in multiple sclerosis—the same considerations govern the surgical approach But we are usually dealing with an adult who is less tolerant of protracted programmes of re-education Just the same, manipulative stretchings and immobilization in plaster may sometimes avoid the necessity for more drastic procedures.

Braces, especially calipers, are quite commonly used both to give stability and to correct deformity but they are better avoided if possible, even if the patient has a queer gait, as however much they help they are undoubted encumbrances on a weakened limb Ankle clonus, usual in these conditions though rarely marked in cerebral palsy may make toe raising devices impractical.

Tenotomies, tendon transfers, and muscle slides may occasionally be necessary exactly as in cerebral palsy In multiple sclerosis however tenotomies for tight contractures are commonly necessary In this condition even more than in paraplegia following spinal injuries, recurring flexion contractions in the legs are commonly troublesome and may be agonizingly painful. Tenotomies may stop the involuntary limb movements but do not necessarily abolish the painful cramp Anterior rhizotomy is a procedure developed in war time through the demands of spinal paraplegics and is of course in the province of the neurosurgeon. Here it may be said that usually section of the anterior nerve roots from the 10th thoracic to the 1st sacral inclusive will abolish the painful contractures. The operation is carried out in stages, one side at a time. A real difficulty is the upset of bladder function that not uncommonly results but often bladder dysfunction is present already and in any case it may not be too great a price for freedom from these painful flexion contractions.

The spinal paraplegic may often be taught to walk in calipers subsequently—the operation of course paralyses his legs but does not disturb their sensory side or produce trophic changes.

The multiple sclerosis patient is never likely to walk after such a procedure and it should not be advised until he has become reconciled to a wheel chair existence at best.

Recently what seems at first sight a terribly drastic approach has brought comfort and some serenity to a significant number of patients. Total ablation of the offending leg, and if necessary of both, needs some courage on the part of both patient and surgeon

but, viewed dispassionately it stops the contractions, it does not interfere with bladder or bowel function, it makes nursing attention easier and it lightens the load on the arms of the nurse and of the patient himself His arms moreover are often weakened by the disease so that, spared the weight of his legs, he can more easily shift himself about in bed or in his chair It is important that the ablation be a disarticulation at the hip. If not, any stump—however small—can still contract painfully and impede nursing attention and the exercise of the natural functions.

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CHAPTER XX

PERIPHERAL NERVE INJURIES

O J VAUGHAN-JACKSON

THESE physical lesions have always presented difficulties of classification but, though it has not been immune from criticism, Seddon's (1942) classification is, in practice a very useful one He puts them in three groups.

(a) NEUROTMESIS. Strictly this means anatomical division, partial or complete of the nerve, complete of the affected axons but its meaning is extended to include anatomical interruption of axons by intraneural scarring such as that following the "commotio" of a gun shot wound, accidental injections of drugs, ischaemia, or traction injuries. The essential is that regenerating axons cannot pass unaided into the distal endoneurial tubes.

(b) AXONOTMESIS. Resulting as a rule from external pressure, the axons are interrupted and they degenerate, but the gross structure of the nerve is not divided. If therefore the damaging factor is removed the regenerating axons can progress distally down their own tubes to their own end-organs.

(c) NEURAPRAXIA. Here there is transient abolition of conduction in the axons, without their death—a physiological division. The usual cause is pressure and the tourniquet palsy is the classical example. Usually the motor fibres are most affected.

We must realize that in any given nerve lesion the surgeon may be dealing with any or all of these types of injury It is clear that Axonotmesis and Neurapraxia are potentially fully recoverable lesions. Neurotmesis is not. All three types of injury by abolishing nerve conduction, produce a similar clinical picture initially The difficulty is to know when we are dealing with an anatomical division which cannot recover unless we perform an anatomical repair Time, it is true will tell us but we should know at the earliest possible moment if repair is to have the best chance of success. The local pathological changes must be related to the clinical findings.

It is clear that motor and sensory loss, partial or complete, distal to a wound, especially a penetrating wound, in the course of a peripheral nerve is strong presumptive evidence of anatomical division of the nerve and it should be explored. In the case of a compound fracture the nerve may have been only contused or compressed but the necessity for carrying out a surgical toilet of the open fracture usually affords the opportunity for examining the nerve It is in closed injuries that difficulty arises. The risks of exploring an injured peripheral nerve immediately are very seldom so great as to make the procedure unjustifiable and if in fact an anatomical division is revealed the procedure will have been justified. It is, however when no such division is found that we are apt to find ourselves regarding an injured but intact nerve with a wild surmise totally undecided as to what the damage amounts to and with a more or less dignified withdrawal the only course open to us. True in such circumstances we do *know* that there is no actual division and this is a worth while piece of information, but we may yet have to re-explore, resect, and suture. Moreover except in the case of absolutely clean cut division immediate suture is not the best treatment since our careful repair may be

engulfed in intra and perineural fibrosis extending some way up and down the nerve *after a diffuse injury and a further exploration, resection, and suture will be necessary* With closed injuries then there are cogent reasons for waiting and seeing. But we must be able to interpret what we are seeing.

THE CLINICAL FEATURES OF NERVE INJURIES

Motor Function

Complete division of a peripheral nerve produces complete motor paralysis and sensory loss *in its territory* The catch in this statement of the obvious lies in the last three words As long as we are alive to the fact that nerve territories overlap variably and *commonly* show wide differences from the text book descriptions there need be no confusion with what appears at first to be a partial lesion but is actually complete, nor with what appears to be a complete lesion of one nerve plus a partial lesion of another but is actually a lesion of one nerve alone. This variable overlapping is most important in the nerves of the upper limb and especially in the median and ulnar Rowntree (1949) analysed these anomalous innervations in the case of the median and ulnar nerves and for details the reader is referred to his work. Suffice it here that 20 per cent of cases revealed some anomalous innervation, and that every gradation, from complete ulnar to complete median innervation of the small muscles of the hand, was found.

There are additional traps for the unwary Victims of partial paralyses of a limb are quick to find out what they can achieve with what is left and rapidly develop ways and means of achieving their object, including trick movements with which they deceive themselves and their advisers.

First, intact muscles may still be able to move the limb bones so that the origins and insertions of paralysed muscles are moved relative to each other Increasing, in this way the distance between their attachments will produce a movement, say of the digits, which looks exactly as if the paralysed muscle had contracted. Especially is this so if the paralysed muscle has become inelastic through fibrosis, or is tethered.

Second, rebound movements are another source of error If say flexor pollicis longus is paralysed sudden release of full extension of the terminal phalanx results immediately in a flexion movement brought about by the recoil elasticity of all the soft tissues, especially the joint capsule and ligaments.

Third, substitution movements may be confusing. For example the flexor action, on the elbow of the forearm flexors and extensors may simulate weak contraction of a paralysed biceps.

Sensory Function

In diagnosing the extent of nerve injury only touch and pain require testing. Though less refined methods are commonly useful in mapping sensory loss roughly the Von Frey hair which bends at a given pressure is the accepted instrument for accurate recording (Fig 364) *A sharp needle is used to map loss of pain sensibility* Here again nerve territories overlap considerably (and variably), so that after a nerve division there is always an area of blunting of sensation (still supplied by a neighbouring nerve) around the area of definitive anæsthesia. Sometimes the overlap is such that there is no sensory loss at all.

It is clear that reliance on textbook anatomical descriptions has pitfalls and nerve blocking may be necessary to untangle an anomaly of innervation Bremner Highet (1942) explored the possibilities of selective blocking of peripheral nerves with procaine.

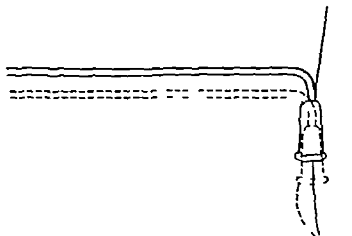


FIG. 364 *The Von Frey Hair* Depression of the handle causes the hair to bend when it touches the skin. Identical pressures are achieved each time by bending the hair till it just touches the rim of the holder

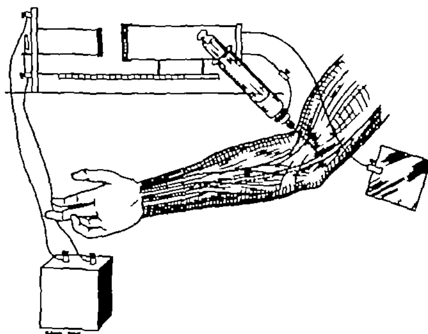


FIG. 365. Essentials of apparatus for nerve blocking (Highet).

The aim is to block only *one nerve*, be it the injured one or an intact neighbour so the purpose is to achieve an intra-neural injection. A special hypodermic needle, (Fig. 365) insulated except for its extreme point, is attached to a faradic coil and the

nerve sought with its point at a convenient place, e.g. the ulnar at the elbow When the point finds the nerve the appropriate response to the electrical stimulus is apparent, and the injection can then be made. If instead, an injection is made only in the neighbourhood of the nerve in question, other adjacent nerves may be affected by diffusion and the test vitiated.

By blocking nerves singly together or seriatim, it is possible to determine, say that all the intrinsics are supplied by the ulnar nerve and that therefore persisting contraction in the thenar muscles is not incompatible with a complete median lesion.

Other methods of electrodiagnosis are available. The fact that denervated muscle loses the power of contracting in response to a sufficiently intense faradic stimulus is the basis of the time honoured test for the Reaction of Degeneration (R.D), But too much must not be read into this test. The reaction is not present at all for some three weeks after injury In partial lesions it gives us no information as to how much muscle is still innervated and alteration in the local tissues (e.g. in a Volkmann s Ischaemic contracture) may completely confuse the issue or even prevent any response being obtained at all. Modern apparatus (Ritchie 1948) enables us to employ electrical stimuli of known duration and intensity each variable at will within suitable limits and it is from these that intensity-duration curves can be constructed which not only show different characteristics for normal and denervated muscle but also allow us to trace the progress of reinnervation (Fig. 366).

Electromyography is very much a research technique but it has its place in the management of peripheral nerve injuries in specialized units. It is a delicate means of detecting minor degrees of denervation and it provides the earliest evidence of motor recovery

Trophic and Vasomotor Changes

There remain for consideration the trophic and vasomotor changes following a nerve injury Though of less importance in the diagnosis of a nerve injury they can be useful in charting recovery

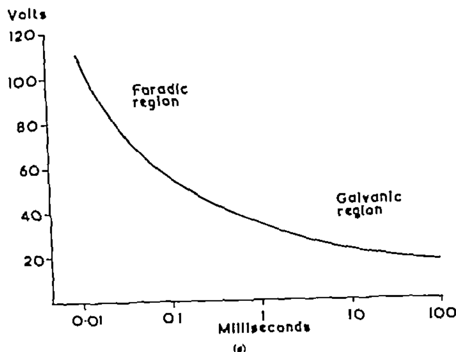
The first change after a nerve is divided is flushing, warmth, and dryness of the skin in the analgesic area. Over a period of some weeks the skin gradually becomes locally *poikilothermic and varies in temperature with its environment, usually being colder than* over the rest of the body

Sweating is diminished or abolished over the affected areas and the geography of this loss can be demonstrated dramatically with powders (Quinizarin) which change colour when moist.

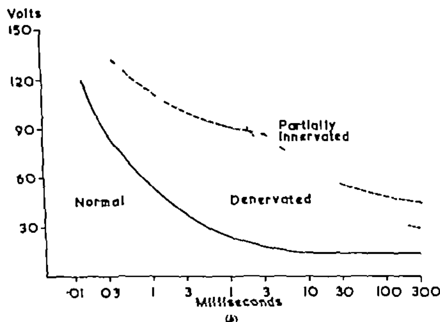
The skin, and tissues generally peripheral to the lesion become atrophied and, especially in the hand, the shining dry atrophic skin, misshapen brittle nails, and wasted finger pulps constitute a classic and familiar picture, added to here and there by the scars or ulcers resulting from unfelt trauma, e.g. cigarette burns (Fig. 367).

THE REPAIR OF DIVIDED NERVES

Repair worthy of the name by natural processes unaided, virtually never occurs. The reason for this is apparent when we study the histology of such attempts at repair If the lesion is a clean transverse cut, *and the ends remain in apposition, fibrosis, especially* interfascicular fibrosis, is at a minimum. The meeting and joining of Schwann cells,



(*a*)



(*b*)

FIG. 366. (*a*) Intensity duration curve for normal muscle. The brief durations (*left*) correspond to Faradic stimuli, the longer (*right*) to Galvanic stimuli.

(*b*) Intensity duration curves showing the altered characteristics in the curves from denervated and partially innervated muscle.

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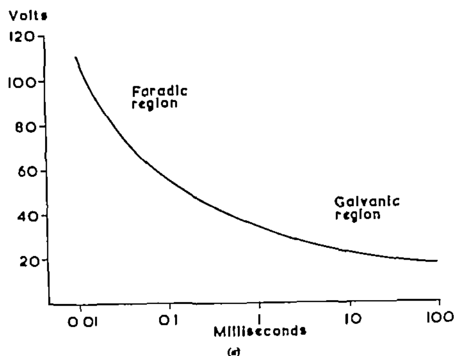
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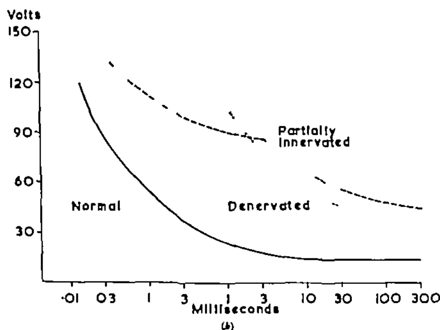
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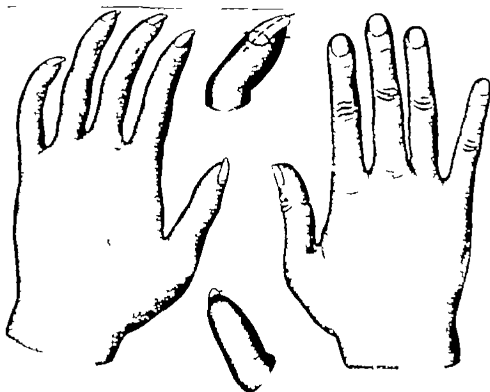


FIG. 367 The hand on the left shows the typical smooth shiny skin without wrinkles, wasted finger pulps and curved nails. Right hand normal

growing from each cut surface, is not prevented and where this has occurred axons from the proximal stump can grow along these lines of Schwann cells into the distal endoneural tubes to replace the distal axons which have disappeared in the process of Wallerian degeneration (Fig. 368).

Commonly nerve injuries are diffuse and not clean cuts. Perineurial and inter fascicular fibrosis is marked and the divided ends are sealed off by fibrous tissue which may be in continuity or otherwise The perineurial fibrosis would not matter and indeed might even facilitate subsequent end to end suture but the terminal fibrous tissue *on the proximal stump deflects regenerating axons so that they are twisted this* way and that and a so-called "false neuroma" results. Some are strangled further proximally by the interfascicular fibrosis. In traction injuries all components of the nerve suffer and thickening and fibrosis of all structures including blood vessels may extend over a considerable distance (Fig. 368).

Whatever anatomical continuity may be established physiological conduction never is unless we can circumvent the evils of fibrosis. The basic aim then is to convert the fibrotic lesion in each stump into a clean transve[illegible] [illegible]gh unfibrosed nerve and to bring the opposed ends into apposition directly, [illegible] by means of some form of bridge for the gap.

Before we set about achieving this by surgical means we must know when and how we should interfere.

It is apt to be thought that if we know the average rate of regeneration we should only have to wait so long after any particular nerve has been damaged and if no recovery had occurred we should then explore and repair. Unfortunately while many valuable

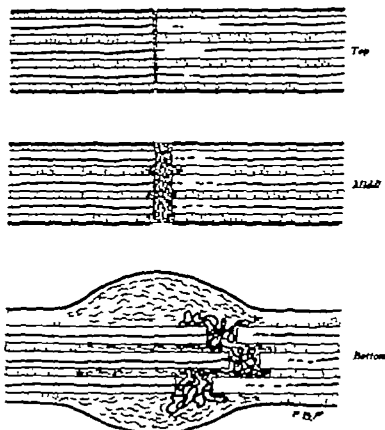


FIG. 368 Diagram. *Top* Cleanly divided nerve. Close apposition of ends. Axons can grow (*left to right*) into distal endoneurial tubes.

Middle Ends not in apposition. Fibrosis between them prevents axons crossing the gap

Bottom In diffuse lesions axons "thwarted" by fibrosis wander aimlessly. A false "Neuroma" results.

figures have been determined for the rate of regeneration they provide no reliable guide for the clinician. There are too many variables. The rate of regeneration varies widely (e.g. from 0–22·4 cm. in 200 days—Bowden and Sholl) It varies with the site of division—the more distal the slower in general. It varies with the amount resected. The level of entry of nerves into muscles is variable and their intramuscular lengths are little known. To say then, that the average rate of motor regeneration is 1·5 mm. per day may be true but this knowledge must be applied critically

OPEN INJURIES of nerves present no great difficulties in deciding the line to adopt. Either the nerve is seen to be in continuity in which case no amount of peering or palpating will make us any the wiser and we must close the wound and wait and see, or *it is seen to be divided in which case a primary or delayed suture (2–3 weeks later when* the extent of fibrosis up and down the nerve can be assessed) is called for

There are other reasons for waiting rather than carrying out a primary suture. The nature of the wound may make adequate mobilization of the nerve for suture

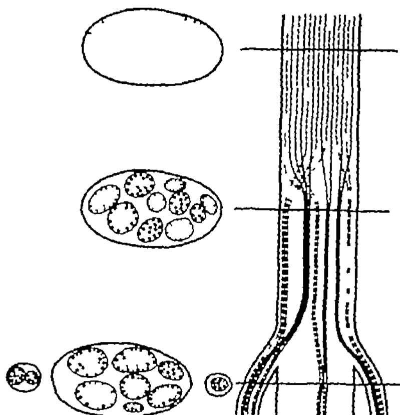


FIG. 169 Purely diagrammatic representation of a mixed nerve. Clearly the higher the lesion the greater the scatter of peripheral effects. Low partial lesions may *have the same results as division of actual branches*

impossible A wound will be potentially or probably infected and no nerve suture will succeed in the presence of infection. These considerations apart, the sooner after the extent of damage is established (2–3 weeks) that we carry out our repair the better the prognosis.

IN CLOSED INJURIES a transient paralysis can often be distinguished from that of an *anatomical division firstly by the relative escape of the sensory side with complete* motor paralysis, and second, by evident recovery Partial anatomical lesions may need careful consideration to distinguish them.

With complete degenerative closed lesions it is known that division of the nerve has rarely occurred except in about 20 per cent of radial nerve injuries. In these then we

t rely with mental reservations, on a deadline for exploration calculated on the very rate of 1 5 mm. per day

Vith incomplete degenerative lesions much depends on when the case is seen. If it ot seen early it must be remembered that the incompleteness may be due to some very and if exact information is lacking about the initial findings we have no alterna to waiting. If the incompleteness does not indicate a transient lesion it means a al division, provided we are clear that innervation anomalies are not at fault

Certain pointers may help A partial division low in the nerve s course will pick off culi which are actual branches but which have not yet left the trunk. Specific cles or areas of skin will then be affected. A similar partial division high up will off motor and sensory fibres destined for many branches and a scatter of paralysis sensory loss will be evident (Fig. 369).

Technique

A tourniquet (pneumatic) is advisable. As these repairs are apt to take a long time always safer to deflate the tourniquet at intervals and re-apply it (after the circulation been free for 5–10 minutes) as often as may be necessary however tiresome this may since estimates of safe duration of tourniquet pressure are unreliable Tourniquet les, though not common, nearly always come as a great surprise to all concerned e all seem to be well within the so-called safe duration limits. There is a tendency the cuff to be inflated to quite unnecessary pressures—it is sufficient to exceed itly the arterial blood pressure. The realization that when muscular assistants wind arch bandages tightly round limbs no one has the remotest idea of the real pressure luced should be enough to damn their use as tourniquets. However this is not the e thing as the legitimate use of an Esmarch bandage to exsanguinate a limb before ting a proximal pneumatic tourniquet

The nerve should be explored above and below the lesion and traced into the area carring (Fig. 370). This may reveal—

1 An apparently normal nerve—we excise the scar tissue as completely as possible, e the wound, and wait.

2. A nerve with a "tough" quality thicker generally though sometimes thinner n normal. This sort of appearance results from traction injuries. The lesion is often nsive in length and may go beyond the limits of the naked eye abnormality Nothing excision and suture is likely to avail and this is often impossible since too great a to be bridged will be left The critical lengths of gap beyond which it is impossible arry out a hopeful suture have been worked out by Zachary (1954) for the major nerves.

3 A "neuroma." Whether this is fusiform or lateral (betokening an anatomically omplete lesion) the procedure depends upon whether the "neuroma" is soft, in which it is worth waiting for further recovery or dense and hard when excision back to lthy nerve fibres and suture is called for In the case of excision of a lateral neuroma gap may be bridged by a graft because end to end suture with "caterpillaring" of the ct portion of the nerve is not satisfactory There is no epineurium on the faces the stumps mobilized off the intact portion of nerve trunk, and sutures here will nage nerve fibrils more or less (Fig. 371). It may be hard to decide whether excision is icated and a series of trial sections may be made transversely into the neuroma. If

the "neuroma" is mostly fibrous tissue excision will be necessary—and this is usually the case.

4 A frank division with two "neuromata"—a large one on the proximal stump and a smaller on the distal. These have to be resected.

The actual resection of the neuroma is carried out after serial sections, coming proximally in the proximal neuroma and going distally in the distal, have revealed a

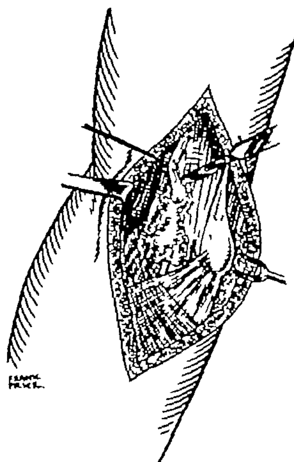


FIG. 370. The nerve is identified above and below the scar tissue and traced into it.

normal cross section free of fibrous tissue (Fig. 372) What is normal in the distal section is not quite the same as normal in the proximal where normal bundles "stand proud" of the cut surface (Fig. 374). *On the distal cut surface the bundles are wasted by Wallerian* degeneration and are much less prominent and the decision where to resect may be more difficult. Once the length of the gap is defined it is necessary to mobilize the nerve to a degree sufficient to allow approximation of the cut ends without tension. While it is relatively safe to mobilize a considerable length of nerve, because of the adequate longitudinal intraneural vascular anastomosis, there is no point and some risk in overdoing it, as may happen if the mobilization is done before the resection.

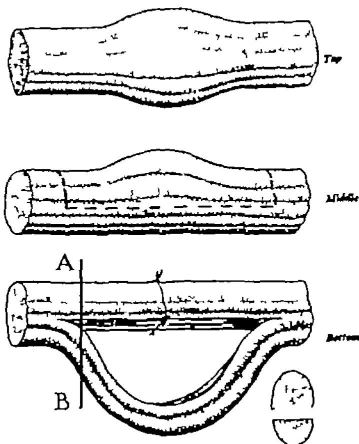


FIG. 371 Diagram. *Top* Fusiform "Neuroma.
Middle Lateral Neuroma," area to be excised is dotted.
Bottom Section t *A B* shows fibrils unprotected by epineurium. "Caterpillaring," as shown, is not as satisfactory as filling the gap by a graft.

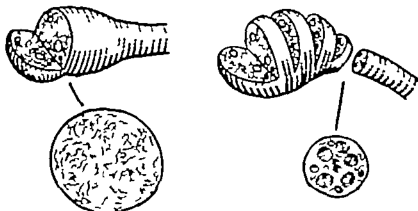


FIG. 372. Trial *sections of "Neuroma till normal cross section is reached.*

Subsequently the limb is held in plaster for 3–4 weeks to avoid all risk of inadvertent stretching, sudden or slow of the healing nerve.

There remains the problem of the gap which is too large for repair by end-to-end suture after ordinary mobilization. Several solutions are possible—

(a) **Bone Shortening.** Occasionally but only occasionally a bone can be shortened to gain length at the gap. In practice this means the humerus only in lesions of the median or radial nerves. In the femur the rather poor results of sciatic nerve suture would not justify the extra risks involved. If one happens to have a median nerve lesion in association with an ununited fracture of the humerus—a rare enough association—it would be reasonable to graft the bone deliberately with some shortening. Conceivably with a median nerve lesion and a compound fracture of the humerus it might

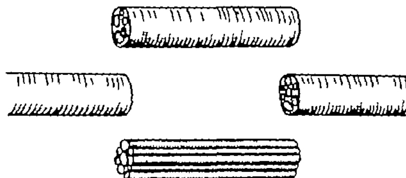


FIG 375 Diagram. Trunk graft (top), a cable graft below

be possible to foresee the need for shortening of the bone which might be encouraged to unite with overlap.

Below the elbow and knee limb shortening is too complex a procedure, with too many risks to commend itself It may be said that bone shortening is of strictly limited usefulness in the repair of peripheral nerves. In the report on Peripheral Nerve Injuries (M R.C. 1954) only 17 cases out of hundreds reviewed were dealt with by this method.

Bulb Suture. This is a procedure of limited though real usefulness. Where the gap is close to or spans a joint the terminal "Neuromata" are simply sewn coarsely together with stout materials with the joint flexed, and the wound closed. The joint is then *slowly* extended by plaster and turn-buckle and on re-exploration later enough length may be found to have been gained to permit direct suture. The risk of traction lesions is obvious but more will probably be heard of this method (Seddon, 1954)

Nerve Grafting. For a long time this procedure was out of favour but the insistent demands of war injuries in 1939–45 forced attention to its possibilities. The results have been a good deal better than was expected.

Heterogenous grafts have all failed. Work continues on the preparation of homografts in an endeavour to prevent their destruction by immunity reactions provoked in the host. Meanwhile autogenous grafts succeed in a limited field of application within which they can be relied on to give results not inferior to those of direct suture

Whether a piece of major nerve trunk is used or several lengths of [illegible] cutaneous nerve or nerves (cable graft), the aim is to have the cross section [illegible] grafts the

same as that of the nerve being grafted (Fig. 375). Clearly it may not be at all easy to find sufficient material for the graft. With a cutaneous nerve a length well above its area of distribution is chosen since once in the branching area the cross section diminishes with each branch. The nerves usually employed are the internal cutaneous of the forearm proximal to its bifurcation at the elbow the superficial radial between elbow and wrist, the sural above the lateral malleolus and the internal saphenous in the thigh.

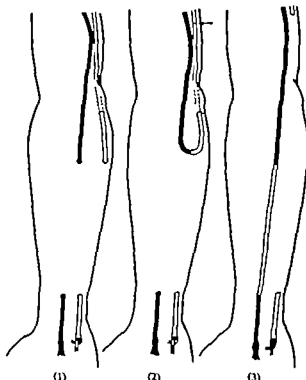


FIG. 376. Nerve Pedicle Graft (Strange).

(1) Large gaps in median and ulnar nerves.

(2) Ulnar trunk sacrificed, joined to proximal median stump it is sectioned *proximally so that its axons will degenerate and* "empty" the endoneurial tubes.

(3) Later the graft, having gained a new blood supply from the median, is mobilized, swung distally and the suture completed.

A segment of main nerve trunk is seldom available unless two main nerves are damaged and one can be sacrificed for the repair of the other For example a segment of ulnar nerve may be used to bridge a gap in the median With *thick* grafts of this kind, necrosis of the graft may occur before revascularization is complete. To avoid this risk a nerve pedicle graft as described by St. Clair Strange (1947) may be used (Fig. 376).

It is clear that the type of injury that will cause large gaps in nerves is likely to cause large gaps in other tissues as well and considerable preparatory plastic work may be necessary to get rid of scar tissue and provide a full thickness skin cover Without a satisfactory bed to lie in, the graft will probably fail. It may be impossible to achieve a

satisfactory bed and if a pedicle nerve graft, which would at least survive, is not feasible, the only solution may be to bypass the scar through a longer route in healthy tissue, mobilizing the nerve stumps and using a longer graft to do so (Fig. 377) (Seddon, 1954)

The actual suturing of the graft calls for no particular comment it is a matter of meticulous and patient needlework The use of plasma clot to stick the graft and nerve ends together simplifies matters (Young and Medawar 1940) but a tendency for the ends to evert obstinately may temper one's satisfaction.

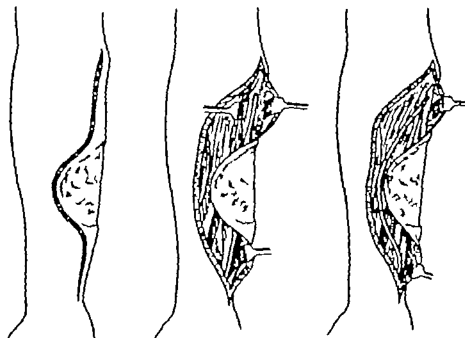


Fig. 377 The method of by-passing a scar by mobilizing the nerve stumps and grafting (ulnar nerve in the forearm).

Results of Nerve Repairs

The results that may be expected have been worked out mainly on battle casualties peace time injuries may produce better figures In general there is a useful degree of recovery in about 50 per cent of cases. Radial nerve injuries do quite well but about one third have persisting loss of finger dexterity In the median nerve it is necessary to judge recovery in the thenar muscles somewhat separately from recovery in the long flexor group. Repair of high lesions may be well worth while even if the thenar muscles do not recover

Ulnar nerve repairs have an unjustifiably poor reputation. Even if full abduction and adduction of the digits by the interossei is not achieved useful intrinsic action commonly is.

In the leg useful strength is regained in the calf even in high lesions of the sciatic nerve in about half the number of cases Imperfect as sciatic nerve repairs admittedly may be the old idea that a divided sciatic nerve presaged an amputation is false. Enough useful function can usually be attained to avoid any such necessity The external popliteal

nerve seems to recover very much according to the level of injury Low injuries generally do well and high ones badly

In brachial plexus lesions there is good spontaneous recovery in lesions of the roots and trunks of C5 and 6 and of the posterior cord, while lesions of the medial cord (C8 and T1) do badly Even so recovery is mainly in proximal muscles and it seems probable that irreversible changes occur in the distal ones before regenerating axons can reach them.

Exploration of brachial plexus lesions showed that the nerve trunks are rarely actually divided and the results of repair are uniformly bad. Occasionally repair of the upper trunk may succeed.

In general in peripheral nerve injuries the lower the lesion the better the result, both motor and sensory Higher injuries do worse from a motor point of view owing to irreversible changes in distal muscles. A long delay before repair worsens the prognosis. Motor recovery is unlikely after 18 months and sensory after 2½ years The complications —tension, traction injuries, etc., and the necessity for grafts—that accompany resections, vary as the length of the resection and affect the prognosis accordingly—short resections do better than long.

The After-treatment of Peripheral Nerve Injuries

Whatever the nature of the lesion and its treatment or repair after treatment is clearly of very great importance. The main problem is to maintain joint mobility and to prevent contracture while healing proceeds in the nerve. In the immediate post-operative period the repair must be protected from tension, sudden or gradual, by a rigid splint, but every bit of the limb which can be actively and passively moved without this risk should be exercised constantly in this manner In between exercises contractures in the position of paralysis are avoided by splinting and if the splint can be of the light "lively" type, which can be overcome by normal muscles but springs back into the desired position once they relax, we can combine effectively four objectives—

1 The exercising of normal muscles.
2 The maintenance at rest of the position of function.
3 The prevention of continual stretching (e.g. by gravity) of paralysed muscles, which if uncorrected prejudices recovery
4 The prevention of joint contracture.

A particular application of maintaining the position of function is seen in combined median and ulnar nerve lesions. In these all the intrinsics are knocked out and a claw hand will develop. With the metacarpo-phalangeal joint hyperextended the extensor communis digitorum cannot extend the inter phalangeal joints. A so-called Knuckle duster splint keeps the metacarpo-phalangeal joint to 180 degrees or a little less and the patient can then extend his fingers despite his intrinsic paralysis (Fig. 378).

Electrotherapy has been found to make very little difference to the rate of recovery unless it is started early and used assiduously—at least daily Its greatest value lies in the treatment of paralysis of the hand intrinsics.

Occupational therapy is clearly of the greatest importance. Any patient with a repaired nerve has inevitably a relatively long period of disability Exercises, and physiotherapy are—let it be faced—boring. Occupational therapy need not be and

should not be. Apart from this the functional result after a nerve repair is going to be imperfect. Any compensatory skill the patient can acquire will therefore be of incalculable value to him, and the number of such skills occupational therapy can assist him to is limited only by human ingenuity

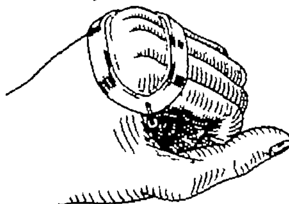


FIG. 378. A simple and inexpensive Knuckleduster splint shaped from acrylic plastic and padded with felt. The palmar cross bar is attached to it at each end by rubber bands whose tension can be varied to suit the individual hand.

IRREPARABLE NERVE INJURIES

That we find ourselves unable, for one reason or another to restore physiological conduction in a damaged nerve does not necessarily mean that we can do nothing. The devices and artifices to which we may resort would fill a sizeable volume on their own and are in any case discussed under Poliomyelitis. Here we may briefly consider a few principles and examples.

First, our objectives are broadly different in the legs and the arms. In the leg stability combined with at least a reasonable free swing, is the aim. In the arm prehension and mobility are the targets and may in certain circumstances outweigh stability in importance, albeit never completely

In the leg, fine movements of the toes and their intrinsic muscles are relatively unimportant A drop foot or a knee which cannot be held extended are very important. In the leg, then, the emphasis is on restricting joint movements, yet some must be retained. In the hand the restoration of the ability to oppose the thumb may restore the power to grasp. The ability to put the hand where he wants it, conferred perhaps by an arthrodesis of the shoulder is useless and merely frustrating to an individual who is then unable to use the hand itself

Each case, however must be judged on its own merits and the selection of the right patient for whom to do anything at all may be as difficult as deciding what actually should be done. Questions of morale, employment, social and domestic background all enter in and must be carefully assessed.

The actual procedures available overlap a good deal but may be roughly grouped

(1) Prevention of Mobility which the Patient Cannot Control

This may be by means of external splints or internal procedures. It may be complete, as in the case of a knee stabilized by a caliper or an arthrodesis. It may be incomplete

as in the case of a drop foot stop or a cock-up splint for a wrist drop, or a tenodesis to prevent hyperextension of the metacarpo-phalangeal joints in combined median and ulnar palsies.

Occasionally an osteotomy may be useful, as when a supracondylar osteotomy of the femur is used to allow a knee to achieve stability in hyperextension.

(2) Restoration of Control of Mobility

External splints of the spring or lively variety may restore a movement as well as stabilizing a joint. In an irreparable musculo-spiral palsy a fixed cock-up splint stabilizes the wrist for function in the cock up position *only*. One has but to do up a shirt button to realize that there is also a "position of function" with the wrist somewhat flexed, a position permitted, and stabilized, by a spring cock up splint, which afterwards moves the wrist back into dorsiflexion.

Tenodeses may produce trick joint movements as well as limiting them, if they bridge more than one joint. To attach a wrist extensor tendon to a forearm bone would merely limit flexion of the wrist. Similarly to attach the tendons of extensor communis digitorum to the forearm bones would permit flexion of the wrist but only so long as the fingers extended at the metacarpo-phalangeal joints. Merely allowing the wrist to drop under gravity would then cause the fingers to extend. The patient has only to learn to drop the wrist slightly in order to open his hand for grasping active flexion of the metacarpo-phalangeal joints in gripping will, because of the tenodesis, cause the wrist to dorsiflex again. This restoration of ability is so important that much thought should be given to the problem before ever a wrist is arthrodesed.

Tendon Transfers. In these the aim is the restoration of normal or nearly normal control either by supplying new motors for the inactive tendons or by re-routing the tendon of an active muscle so that it completely replaces the inactive muscle and tendon.

Under the first heading—an anterior interosseous paralysis will abolish flexion of the terminal phalanges of thumb and index. The simple attachment of the flexor pollicis longus tendon to the conveniently adjacent belly of flexor sublimis digitorum, and that of flexor profundus indicis to the active belly of flexor profundus medii will restore a pinch indistinguishable from normal

Under the second heading, in a median nerve lesion the lost opposition of the thumb is commonly corrected by freeing flexor sublimis to the ring finger passing it around the tendon of flexor carpi ulnaris (or through a tendinous loop fashioned at the pisiform) and thence subcutaneously across the thenar eminence and the dorsum of the thumb metacarpal to be attached to the ulnar aspect of the base of the proximal phalanx. This restores excellently the rolling component of the movement of opposition and there are few more rewarding operations.

These, however are all examples involving one group of muscles, namely flexors. Sometimes we need to transfer a flexor to a paralysed extensor and though this may be perfectly satisfactory questions of muscle balance arise that may be deceptive.

At the wrist, for example Robert Jones in 1917 in cases of permanent radial paralysis, was restoring wrist extension by transferring pronator teres to extensor carpi radialis, and finger extension by transferring flexor carpi radialis to extensor pollicis longus and extensor indicis, and flexor carpi ulnaris to the extensor communis digitorum to middle, ring, and little fingers. Various modifications of this procedure have had their vogue

and some very successful results have been obtained. But it should be noticed that this leaves only palmaris longus as a wrist flexor and this muscle is not infrequently absent. Zachary (1946) pointed out that where palmaris longus was absent the results were

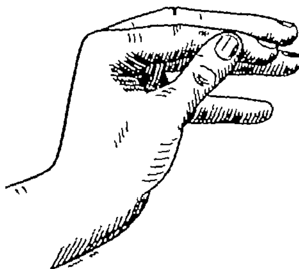


FIG. 379 Characteristic poor functional position of hand after transfer of both wrist flexors to the finger extensors in the absence of a palmaris longus.

deplorable The transplanted wrist flexors, their effective excursion in any case diminished by their new and more round about route, expended virtually all their force in dorsiflexing the wrist and had little or none left for extending the fingers. Quite extreme deformities can be produced in this manner (Fig. 379)

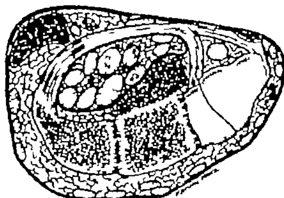


FIG. 380 Cross section of wrist A "lesion" of the carpus is raising the floor of the carpal tunnel and compressing the structures within it

If flexor carpi radialis is left undisturbed it continues to act as an effective synergist, stabilizing the wrist against excessive extension and allowing the transplanted flexor carpi ulnaris to extend the fingers.

It will be realized that the whole problem is intricate and difficult but the rewards of a thoughtful and meticulous approach are considerable.

Slow Compression Nerve Lesions. There remains to be considered an interesting particular group of nerve lesions where the nerves are subjected to slowly increasing pressure An excellent example of this is carpal tunnel compression of the median. Until it was described by Brain, Wright, and Wilkinson (1947) the pains and paræsthesiæ in the median distribution in the hand were doubtless labelled "Acroparæsthesiæ" and some placebo administered. The astonishing thing is how long the true nature of the lesion remained generally unrecognized. Pressure on the nerve within the carpal tunnel may be caused by anything that encroaches on the space available such as old fractures of the lower end of radius, or arthritic changes in the carpal joints (Fig. 380). In the writer's experience chronic tenosynovitis—either rheumatoid, tuberculous, or non-specific—is rarely a cause, though not all would agree. Be that as it may the condition found may vary from no visible abnormality whatever to a well-marked "nip" with œdema of the nerve proximal and distal to it which diminishes while being observed once the transverse carpal ligament is divided (Fig. 381). Nevertheless the symptoms, which are those one

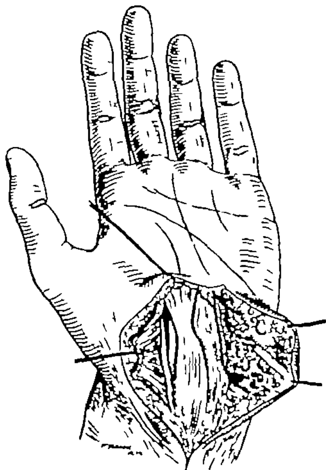


FIG 381 *From Life* Distinct nip in the median nerve on opening carpal tunnel. Note proximal portion of nerve is markedly œdematous.

would expect with a lesion at this level (pain, paræsthesiæ and blunting or loss of sensation in the median distribution in the hand), are almost constantly relieved by simple division of the transverse carpal ligament.

Recently a group of cases of pressure on nerves by "ganglia" have been described. Again it is surprising how they could have failed to be reported years ago since the reporting of one case produced reports of others immediately from other workers.

Seddon describes *pressure on the deep branch of the ulnar in the palm by capsular "ganglia"* arising at or near the pisiform the ulnar has been compressed in its fibro-osseous tunnel at the elbow by a collection of pin head ganglia arising from the margins

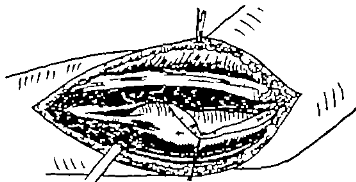


FIG 382 *From Lif* Ulnar nerve displaced over ganglion in common flexor origin which had compressed it against the medial surface of the olecranon. The internal humeral epicondyle is at the right-hand end of the incision.

of the elbow joint and again, between the olecranon and a large ganglion in the common flexor mass (Fig. 382). Perhaps the most entertaining presenting symptom was that of the lady whose index finger always folded uselessly up when she tried to dry her ear Her dorsal interosseous nerve was compressed by and spread out over a ganglion arising in the antecubital fossa.

Clearly treatment consists in removing the cause.

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CHAPTER XXI

AMPUTATIONS AND ARTIFICIAL LIMBS

LEON GILLIS

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by infiltration of procaine or in a few selected cases, by freezing the limb In this method the entire limb is packed in broken ice for several hours prior to operation

Hæmostasis. The generally used method of controlling hæmorrhage is a tourniquet, although in large operations or when the vessels are diseased it is sometimes preferable to secure the vessels by dissection before proceeding with the amputation

Sites of Election

Upper Limb (Fig. 383)

(a) Shoulder

Amputations of the humerus at a point 1 in. below the tip of the acromion gives a better result than disarticulation of the shoulder joint.

(b) Upper Arm

Optimum level is 8 in. below the tip of the acromion, although a stump of 5 in. from the tip of the acromion can be fitted with a useful artificial limb

(c) Forearm

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Lower Limb (Fig. 384)

(a) Hip

For stumps of less than 4 in. from the top of the greater trochanter a prosthesis of the tilting-table type will probably be fitted. This is also the case in disarticulation at the hip However leaving the head, neck, and greater trochanter of the femur gives a more secure tilting-table socket than disarticulation of the hip, and should be practised in preference to the latter operation.

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(c) Below-knee

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This mutilating operation is rarely performed. Among the few indications the usual one is the presence of a large malignant chondrosarcoma of the shoulder girdle. The whole upper limb, the outer end of the clavicle and the entire scapula are removed in one piece

Preliminary A blood transfusion is started after the patient has been anæsthetized, and before the operation is begun. The patient is placed on his sound side close to the edge of the operating table Littlewood's technique from the front is the simplest and most expeditious method of performing this operation. The type of incision will vary

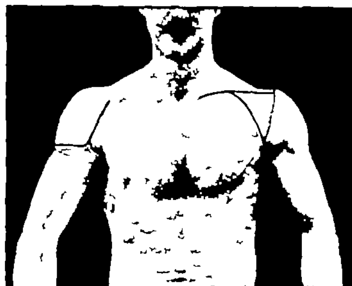


Fig. 387 Right side shows the incision over a subscapular amputation and the left side shows the incision for forequarter amputation.
("Operative Surgery" Milne and Wilkie, Oxford University Press)

according to the site of the tumour As a rule two incisions are planned—a cervico-scapular and a pectoro-axillary (*see* Fig. 387).

The Operation

(1) The cervico-scapular flap is made by commencing the incision near the outer border of the sterno-mastoid attachment to the clavicle and carrying the incision along the clavicle, over the prominence of the shoulder along the posterior axillary fold to a point between the angle of the scapula and backwards to about 2 in. (5 cm.) from the spine

(2) This large flap of skin and subcutaneous tissue is turned back, exposing the posterior surface of the scapula together with the muscles which attach it to the spine.

(3) The trapezius and the latissimus dorsi muscles are divided together with the levator anguli scapulæ and rhomboid muscles.

(4) Next, the scapular attachment of the serratus anterior and omohyoid muscles are severed. (At this stage several large vessels will require ligature, i.e. branches of the supra-scapular and posterior scapular arteries.)

(5) The clavicular attachment of the sternomastoid muscle is separated with a knife.

(6) This is followed by sub-periosteal dissection of the clavicle with an elevator

(7) A Gigli saw is then passed under the clavicle and the bone is divided just lateral to the sterno-clavicular joint, exposing the subclavius muscle whose severance will enable the whole upper extremity to fall away from the trunk. This last manœuvre places the subclavian vessels and the cords of the brachial plexus on the stretch, and they can now be easily seen.

(8) Two artery forceps are placed on the subclavian artery and ligatures are applied by means of an aneurysm needle on each side of the forceps The ligatures are secured and left a good length

(9) The subclavian artery and vein are then divided between the two artery forceps The cords of the brachial plexus are cut with scissors close to the spine. There is no advantage in injecting a local anæsthetic for these nerves before division.

(10) The operation is now continued by making the anterior pectoro-axillary flap by reflecting the skin as far forward as is necessary

(11) The operation is completed by dividing the pectoralis major and minor muscles (Usually these muscles need be divided only at their insertions, unless that part of the humerus or scapula is involved in the disease.)

The fore-quarter will now come away easily from the thoracic wall (The thoracic boundary of the axilla with the contents of lymphatic glands can then be removed, if they are diseased.)

(12) The flaps are next closed in layers, and the skin with interrupted sutures. Tension sutures will usually be found necessary A firm dressing is applied.

This operation leaves the unfortunate patient with a very ugly sloping upper part of the chest wall. A pad will be required suspended from the neck, to give the appearance of a shoulder from which a coat can hang.

Later on scoliosis results from the unbalanced weight, but this can be counteracted, to some extent, by post-operative physiotherapy such as postural exercises

(2) Disarticulation at the Shoulder

(1) The arm is abducted and rotated well outwards

(2) An incision is made, beginning immediately external to the coracoid process, and carried through the clavicular fibres of the deltoid as far as the lower border of the pectoralis major This incision goes down to the bone.

(3) The cephalic vein and branches of the acromio-thoracic and anterior circumflex arteries are divided and ligatured.

(4) The anterior fibres of the deltoid pectoralis major and the long head of the biceps are then divided

(5) The incision is carried round the outer aspect of the arm, through the lower fibres of the deltoid, towards the posterior axillary fold. This portion of the incision is also made down to the bone.

(6) Beginning at the lower end of the original vertical incision, the skin and fascia on the inner aspect of the arm are divided until they meet the outer incision.

(7) The inner incision is then carefully deepened, and the main vessels dissected out, secured, ligatured, and divided.

This mutilating operation is rarely performed. Among the few indications the usual one is the *presence of a large malignant* chondrosarcoma of the shoulder girdle. The whole upper limb, the outer end of the clavicle and *the entire scapula* are removed in one piece

Preliminary A blood transfusion is started after the patient has been anæsthetized, and before the operation *is begun. The patient is placed* on his sound side close to the edge of the operating table Littlewood's technique from the front is *the simplest* and most expeditious method of performing this operation. The type of incision will vary

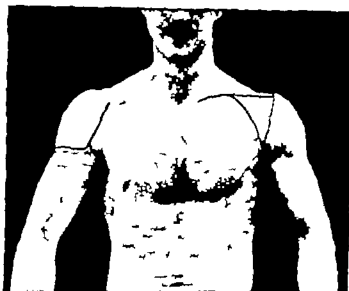


FIG. 387 Right side shows the incision over a subcapital amputation and the left side shows the incision for a forequarter amputation.
("*Operative Surgery*" *Milne and Wilkie Oxford University Press*)

according *to the site of the tumour As a rule two incisions are planned—a* cervico-scapular and a pectoro-axillary (*see* Fig. 387)

The Operation

(1) *The* cervico-*scapular flap is made by commencing the incision near the outer* border of the sterno-mastoid attachment to the clavicle and carrying the incision along the clavicle, over the prominence of the shoulder along the posterior axillary fold to a point between the angle of *the scapula* and backwards to about 2 in. (5 cm.) from the *spine*

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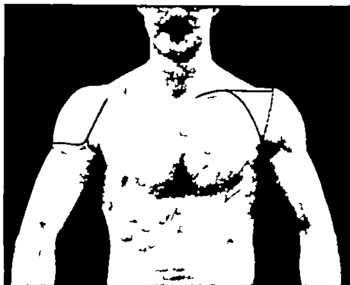


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(7) The inner incision is then carefully deepened, and the main vessels dissected out, secured, ligatured, and divided.

(8) The deltoid muscle is dissected up, by keeping the knife close to the bone, so as to avoid the posterior circumflex artery

(9) The arm is rotated outwards and the capsule is divided together with the subscapularis muscle.

(10) The arm is now rotated inwards, and the muscles, attached to the greater tuberosity are separated, namely the supraspinatus, infraspinatus, and teres minor

(11) Next the knife is passed behind the bone to separate the long head of the triceps, and then down, on the inner side, to divide the muscles in the bicipital groove—the biceps, coraco-brachialis, latissimus dorsi, and teres major

(12) After removal of the arm a large pack is inserted into the cavity All the small bleeding points are carefully caught up and ligatured. No attempt is made to inject any of the sectioned or divided nerves, which have all been cut short. The wound is carefully closed in layers with a drain at the lower end.

(3) Hand and Fingers

INDICATIONS FOR AMPUTATIONS

It is unwise to make dogmatic statements concerning amputations of the fingers. Each case should be judged according to the nature of the lesion and the presence, or absence, of the remaining digits, due consideration being given to the occupation of the patient. If possible in the case of an artisan, preserve the fourth and fifth digits. It is difficult, if not impossible, for a workman to hold a hammer or other tool satisfactorily when these fingers have been amputated. If a phalanx, amputated at the base, proves of little value, re-amputation can always be made at a later date. After returning a hand-injury to work it is surprising to note the amount of functional improvement that takes place within 6 months. Without sufficient tissue no useful function can be achieved subsequently Therefore, as a primary line of treatment, conservation of tissue must be the keynote in surgery of the fingers and hands.

(I) ACUTE TRAUMA. It is surprising how pronounced is the power of recovery in the hand, so that it is better to avoid immediate amputation unless a finger is literally hanging by a thread. Operation, therefore, should be postponed until there is unmistakable evidence that the finger or part of it, will not survive Unless the injury is complicated by sepsis, no formal amputation should be done for such injuries, but the doomed portion should be separated at the point at which injury has occurred, the bone trimmed, and the skin cover fashioned by flaps.

Exceptions (*a*) Severe compound fractures, involving joints which are irreparably damaged and soft tissues which have been lacerated. In such injuries, when there is *unmistakable evidence* that no useful function is to be achieved, amputation may be considered. (*b*) When several structures in the finger have been so severed as to be beyond repair e.g. loss of skin, that is, a degloved hand associated with a fracture, severed tendons, and the principal digital nerves.

(II) GANGRENE. Chemical or thermal (electrical) gangrene of the tips of the fingers and hands is more commonly seen than gangrene which is associated with peripheral vascular disease such as Raynaud's disease, Buerger's disease, or arteriosclerosis.

The necrotic tips should be kept dry and infection avoided. If infection ensues it is sometimes necessary to trephine the nail or even occasionally to remove it for drainage If the gangrene remains dry and painless the necrotic portion slowly separates.

Amputation is necessary to assist this process and also in the cases where the gangrene is painful

(iii) INFECTIONS OF THE HAND In sepsis, early amputation need not be considered, for with the use of chemotherapy and antibiotics, it is wise to defer the question of amputation until the damaged septic area has been given an opportunity to recover and then to amputate only when the involved parts have failed to respond to treatment.

In chronic infections which have progressed in spite of chemotherapy and antibiotics, the hand sometimes remains merely a bag of pus and disorganized tissue. In these cases it is clear that no useful function will remain.

Infected fingers, which have passed beyond the acute stage and in which the infection has been controlled, may be considered for amputation if the end result is complete loss of function, and a painful hypersensitive finger A painful hypersensitive finger may remain in this state until the anxiety state of the patient is relieved.

Amputation of the little finger seriously weakens the leverage power by limiting the length of the span of the hand, and it weakens the grip for heavy tools

Fingers which have become involved in an infective process leading to osteomyelitis and suppurative arthritis should be treated with appropriate antibiotics. Occasionally it may be found necessary to amputate a portion of a digit, or even a whole digit, when it is found that no improvement is possible even with surgical drainage Sometimes a finger tip can be saved by removal of the terminal phalanx only and filleting the in fected segment. Amputation in such cases shortens convalescence It allows mobilization of the remaining fingers, while it removes a painful liability

(iv) DEFORMITIES. Stiff and useless fingers which result from both injury and sepsis, form one of the most common indications for amputation.

Such a finger may be fixed in flexion or extension. If fixed in extension, it stands out like a rigid rod, fails to contribute anything useful to the hand in general, except tactile sensation, and by preventing the other fingers access to surrounding objects, impairs their function.

Fingers which should be considered for amputation are those fixed in flexion—usually the result of conservation of digits which have become ankylosed following an infection or trauma, or both—which the surgeon has rightly preserved as long as possible. Even then, however a finger fixed in moderate flexion may be well worth keeping, especi ally the index finger since this occupies the "position of function." For example it has been possible for a surgeon to carry on his work with such a deformity

Occasionally such deformities are accompanied by sensitive scars, and these may occasionally be regarded as an indication for amputation. There are cases in which the flexor tendons are fixed by adhesions so that their action is greatly limited, or even totally abolished, but in which the bands themselves remain loose and supple, allowing passive flexion to take place. Although amputation may be indicated in these cases the patient s personal inclination and his employment should be studied.

There are operations for the substitution of free tendon transplants for a disorganized tendon, but the patient may not be inclined to continue along a doubtful line for a further period. When reconstructive operations fail and it is futile to persevere, amputation is justified. A long-standing Dupuytren s contracture which has failed to respond to treatment may also occasionally require amputation

Apart from these indications, tuberculous dactylitis in adults may occasionally necessitate an amputation.

(v) TUMOURS. (a) Benign. In cases where a simple growth exists and the function has been destroyed, the finger involved is not only a hindrance to the remaining fingers but is unsightly (b) Malignant. Epithelioma and melanoma are well-defined indications for amputation.

We owe a great deal to Sterling Bunnell, for he has taught us that, with careful surgery suture of such structures as digital nerves very often gives excellent functional results where previously amputation was inevitable In our zeal however to preserve a finger or part of a finger we should not lose sight of the possible loss of working time and the inconvenience which can be avoided by a well-planned amputation, where such is *indicated*.

In cases of damage to the finger tips, it is important that a well-padded tactile surface is restored. A large, tender avascular scar covering the tip of a finger is to be avoided at all costs, because the frequent presence of pain and tenderness prevents any function of the finger

These tender scars are extremely difficult to eradicate. They are the origin of a causalgic finger tip, which is most resistant to treatment. True causalgia originating in the fingers is extremely rare. Hugh Griffiths, in a personal communication, comments that he has only seen this condition in civil practice twice in forty years. It is desirable to forfeit a little additional bone so that the soft tactile pad on the front of the finger can be sutured to the dorsum, producing a well-cushioned tactile pad.

GENERAL CONSIDERATION OF TECHNIQUE

As with major amputations, an ideal stump is the aim of the surgeon but in the case of the hand this means not only a mobile, painless stump, but one where mobility and sensation are of far greater importance than in any other situation.

Again, in amputating a limb the aim is to achieve the best function of the stump in conjunction with a prosthesis but with a finger there is no prosthesis to be considered, and a cosmetic appliance is very rarely supplied. In a badly mutilated hand, with a thumb still present but some or all fingers missing, an artificial appliance is occasionally provided so as to enable it to function with the thumb and whatever remains of the finger or fingers.

When considering amputation, each structure in the hand should be given special *attention skin, nerves, tendons, blood vessels, and bone. As with most major amputations*, a good skin covering is essential, especially if that skin is local with good sensation. The palmar skin is more sensitive and more abundantly supplied with free nerve endings, nerve bulbs, and tactile corpuscles than any other part of the hand. It is, therefore, most satisfactory as a covering for the end of the bone. It is also more durable than any other skin. Wherever possible, long palmar flaps and short dorsal flaps should be cut. As with amputations of the limbs, so in the amputation of the fingers there should be sufficient skin to cover the end of the bone without tension and without loss of mobility

If the skin flaps are short, or tight, or fixed, it is wise to shorten the bone further and thus enable it to be covered without tension. Treatment of tendons is important in finger amputations and it should be remembered that tendons have a poor blood

supply derived from blood-vessels of the tendon sheath, and that each phalanx is moved by its own tendon. Fingers are flexed at the metacarpo-phalangeal joints by the lumbricals and interossei muscles, which also extend the interphalangeal joints through the common extensor expansion. The second phalanges and, secondarily the first phalanges, are flexed by the flexor sublimis digitorum, but both the proximal and distal phalanges are flexed by the flexor digitorum profundus.

Since each phalanx has its individual muscle supply it *is not necessary to suture the tendons over the end of the bone* in the manner usually practised, as this produces stiffness. Moreover since the blood supply of the tendons is poor the tendon is apt to slough if the wound does not heal by first intention. If it heals it gives the finger a club-shaped appearance and is apt to diminish, rather than add to its strength. Therefore, both the flexor and extensor tendons are cut and allowed to retract when there is no infection present. They do not form adhesions and do not impair movement. If possible, the tendons should be pulled out before section. The digital nerves should be drawn taut, sectioned, and left to retract slightly away from the suture line. The occurrence of painful neuromata can be minimized by preventing scar tissue, which may result from infection around nerve endings. The amputation should always be performed in a clean field, well away from the devitalized tissue, and the nerve replaced in a healthy bed. The digital arteries should be ligated with fine catgut

The bone should be neatly sectioned, not crushed, either with bone forceps or a metacarpal saw If the end of the bone is inclined to be bulbous it should be trimmed with a file. The flexor and extensor tendons are inserted into the bases of the phalanges, and if possible the available portion of these tendons should be preserved by amputation distal to their insertions. If disarticulation at a joint is inevitable, the bulbous extremity of the bone should be tapered with sharp bone forceps, because the width of the condyle makes the ultimate result unsightly

Certain additional anatomical facts have to be borne in mind when amputating a digit

(1) Position of Joints. The joints do not correspond with the prominence of the knuckles, which are formed by the heads of the metacarpals and bases of the proximal phalanges. The joints are situated respectively [illegible] [illegible] and [illegible] in. distal to the prominence of the knuckles, starting at the proximal joint, working proximo-distally

(2) Position of Digital Nerves. These lie on each side of the finger immediately in front of the digital artery and both artery and nerve lie slightly anterior to the mid plane. In amputations which are proximal to the distal interphalangeal joint, it is important to identify and follow these nerves in order to divide them as high up as possible

(3) The Flexor Tendons. The four tendons of the flexor profundus digitorum are inserted one to each base of the terminal phalanges, after perforating the four tendons of the flexor sublimis digitorum, the tendons of which split and are inserted into the sides of the base of the second phalanx of each finger

These tendons are attached to the anterior surface of the phalanges by fibrous bands (vincula) which may prevent tendons which have been cut over the distal phalanx from retracting. If a flexor tendon is cut proximal to the second phalanx, where it is attached to the middle of the bone, the tendon is free to retract. If the tendon sheath is infected, both sheath and tendon may easily carry infection into the palm, and even the wrist

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Apart from these indications, tuberculous dactylitis in adults may occasionally necessitate an amputation.

(v) TUMOURS. (a) Benign. In cases where a simple growth exists and the function has been destroyed, the finger involved is not only a hindrance to the remaining fingers but is unsightly (b) Malignant. Epithelioma and melanoma are well-defined indications for amputation.

We owe a great deal to Sterling Bunnell, for he has taught us that, with careful surgery suture of such structures as digital nerves very often gives excellent functional results where previously amputation was inevitable. In our zeal however to preserve a finger or part of a finger we should not lose sight of the possible loss of working time and the inconvenience which can be avoided by a well-planned amputation, where such is indicated.

In cases of damage to the finger tips, it is important that a well-padded tactile surface is restored. A large, tender avascular scar covering the tip of a finger is to be avoided at all costs, because the frequent presence of pain and tenderness prevents any function of the finger

These tender scars are extremely difficult to eradicate They are the origin of a causalgic finger tip which is most resistant to treatment. True causalgia originating in the fingers is extremely rare. Hugh Griffiths, in a personal communication, comments that he has only seen this condition in civil practice twice in forty years. It is desirable to forfeit a little additional bone so that the soft tactile pad on the front of the finger can be sutured to the dorsum, producing a well-cushioned tactile pad.

General Consideration of Technique

As with major amputations, an ideal stump is the aim of the surgeon but in the case of the hand this means not only a mobile, painless stump, but one where mobility and sensation are of far greater importance than in any other situation.

Again, in amputating a limb the aim is to achieve the best function of the stump in conjunction with a prosthesis but with a finger there is no prosthesis to be considered, and a cosmetic appliance is very rarely supplied. In a badly mutilated hand, with a thumb still present but some or all fingers missing, an artificial appliance is occasionally provided so as to enable it to function with the thumb and whatever remains of the finger or fingers

When considering amputation, each structure in the hand should be given special attention skin, nerves, tendons, blood vessels, and bone. As with most major amputations, a good skin covering is essential, especially if that skin is local with good sensation. The palmar skin is more sensitive and more abundantly supplied with free nerve endings, nerve bulbs, and tactile corpuscles than any other part of the hand. It is, therefore, most satisfactory as a covering for the end of the bone. It is also more durable than any other skin. Wherever possible, long palmar flaps and short dorsal flaps should be cut. As with amputations of the limbs, so in the amputation of the fingers there should be sufficient skin to cover the end of the bone without tension and without loss of mobility

If the skin flaps are short, or tight, or fixed, it is wise to shorten the bone further and thus enable it to be covered without tension. Treatment of tendons is important in finger amputations and it should be remembered that tendons have a poor blood

supply derived from blood vessels of the tendon sheath, and that each phalanx is moved by its own tendon. Fingers are flexed at the metacarpo-phalangeal joints by the lumbricals and interossei muscles, which also extend the interphalangeal joints through the common extensor expansion. The second phalanges and, secondarily the first phalanges, are flexed by the flexor sublimis digitorum, but both the proximal and distal phalanges are flexed by the flexor digitorum profundus.

Since each phalanx has its individual muscle supply it *is not necessary to suture the tendons over the end of the bone* in the manner usually practised, as this produces stiffness. Moreover since the blood supply of the tendons is poor the tendon is apt to slough if the wound does not heal by first intention. If it heals it gives the finger a club-shaped appearance and is apt to diminish, rather than add to its strength. Therefore, both the flexor and extensor tendons are cut and allowed to retract when there is no infection present. They do not form adhesions and do not impair movement. If possible, the tendons should be pulled out before section. The digital nerves should be drawn taut, sectioned, and left to retract slightly away from the suture line The occurrence of painful neuromata can be minimized by preventing scar tissue, which may result from infection around nerve endings. The amputation should always be performed in a clean field, well away from the devitalized tissue, and the nerve replaced in a healthy bed. The digital arteries should be ligated with fine catgut.

The bone should be neatly sectioned, not crushed, either with bone forceps or a metacarpal saw If the end of the bone is inclined to be bulbous it should be trimmed with a file. The flexor and extensor tendons are inserted into the bases of the phalanges, and if possible the available portion of these tendons should be preserved by amputation distal to their insertions. If disarticulation at a joint is inevitable the bulbous extremity of the bone should be tapered with sharp bone forceps, because the width of the condyle makes the ultimate result unsightly

Certain additional anatomical facts have to be borne in mind when amputating a digit

(1) Position of Joints. The joints do not correspond with the prominence of the knuckles, which are formed by the heads of the metacarpals and bases of the proximal phalanges. The joints are situated respectively $\frac{1}{3}$, $\frac{1}{4}$ and $\frac{1}{8}$ in. distal to the prominence of the knuckles, starting at the proximal joint, working proximo-distally

(2) Position of Digital Nerves. These lie on each side of the finger immediately in front of the digital artery and both artery and nerve lie slightly anterior to the mid plane. In amputations which are proximal to the distal interphalangeal joint, it is important to identify and follow these nerves in order to divide them as high up as possible.

(3) The Flexor Tendons. The four tendons of the flexor profundus digitorum are inserted one to each base of the terminal phalanges, after perforating the four tendons of the flexor sublimis digitorum, the tendons of which split and are inserted into the *sides* of the base of the second phalanx of each finger

These tendons are attached to the anterior surface of the phalanges by fibrous bands (vincula) which may prevent tendons which have been cut over the distal phalanx from retracting. If a flexor tendon is cut proximal to the second phalanx, where it is attached to the middle of the bone, the tendon is free to retract. If the tendon sheath is infected, both sheath and tendon may easily carry infection into the palm, and even the wrist

Therefore the tendon should be held before division and fixed to the periosteum by a stitch. This precaution is not necessary in amputation for infection distal to the first phalanx.

(4) THE TENDON OF THE EXTENSOR COMMUNIS DIGITORUM replaces the dorsal ligaments of the interphalangeal joints.

The following surgical points should be attended to when amputating a phalanx

(1) Amputation is preferable to disarticulation, i.e., it is advisable to remove a part or parts either by sawing or with a sharp bone-cutting forceps rather than by going through the joint.

(2) When disarticulation has to be performed it is unnecessary to stitch the flexor

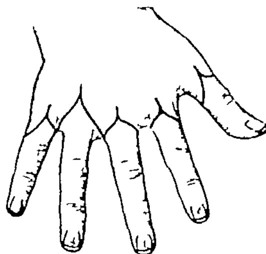


FIG. 388. Surface markings showing incisions used for disarticulation at the metacarpo-phalangeal joints.

and extensor tendons over the face of the stump but the bulbous ends of the phalanx should be trimmed.

(3) As much as possible of the thumb should always be preserved. Practically no part of the thumb can be useless.

(4) The scar should be on the dorsum of the fingers or hand, so as to escape possible pressure.

FINGER DISTAL TO THE METACARPO-PHALANGEAL JOINT A racket incision should be made, the handle of the racket beginning on the dorsum of the hand, just above the centre of the joint and extending distally for ¼ in. (0·6 cm.) below the level of the web The incision should be carried round the finger its lateral parts being extended down to the bone (Fig. 388). The flexor sheath and its tendons are then cut proximal to their insertions. Amputation is completed by severing the extensor tendons distal to their insertions. If a disarticulation at the metacarpo-phalangeal joint is inevitable, the head of the metacarpal bone should not be removed, except in the case of the index and little fingers, when it may be neatly bevelled. In these cases the incision of the handle of the racket should be prolonged upwards for about 1 in. (2·5 cm.) It is also necessary to divide the transverse metacarpal ligament.

PHALANX. The part to be removed is held between the index finger and the thumb and bent to a right angle at the inter phalangeal joint (see Fig 389)

Amputation distal to the insertions of the tendons is preferable to disarticulation An incision, convex distally is made on the dorsal aspect and continued on to the palmar aspect, making semilunar flaps, the palmar somewhat longer than the dorsal until the two incisions are connected up the superficial tissues and the extensor tendon are divided, the bone snipped across and a palmar flap dissected off which can then be neatly approximated to the dorsal flap

The *palmar and dorsal flaps* are dissected upwards. The superficial tissues and the flexor and extensor tendons are then divided, and the bone is denuded at the site where it is proposed to amputate and snipped across. In the case of a disarticulation the capsular ligaments are divided and the joint surfaces separated and the bone end tapered to avoid

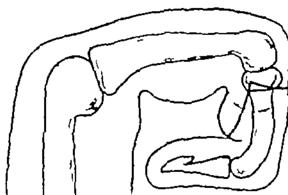


FIG 389 Surface markings showing incision used for amputation distal to the first inter-phalangeal joint or disarticulation at the first inter-phalangeal joint.

a bulbous stump. The tourniquet is then removed and any bleeding points from the digital vessels are caught up and ligated. The palmar flap can then be brought backwards and neatly approximated to the dorsal flap.

THUMB. The thumb is the most important single digit in the hand. The only indications for amputation are gangrene and the rare conditions when the thumb becomes a hindrance, e g. flexion contracture of a useless thumb, which presses *against* and ulcerates the index finger by necrosis in rheumatoid arthritis. Even the smallest portion is of the utmost use Without a thumb the power of *grasp and pinch* is lost, and the value of the hand is lessened to an extreme degree. Every effort should be made, therefore, to save as much as possible of this important entity even if it becomes fixed and acts only as a post for opposition of the other fingers There are many plastic procedures for reconstructing a thumb, and if amputation has been resorted to as much as possible of the length should be saved.

INDEX FINGER. The loss of part or all of the distal phalanx of the index finger is no great handicap to the average individual unless his work involves much tactile activity If on the other hand, a violinist loses the terminal phalanx of his or her digit, this interferes with playing and, therefore, results in loss of earning capacity Should injury or disease necessitate an amputation, proximal to the distal interphalangeal joint, as a

general rule the entire finger should not be sacrificed because the patient can learn to use the short proximal phalanx of the index finger if the basal insertions of the tendons are intact. Except in the case of artisans and labourers, the head of the metacarpal may be removed. It may improve the cosmetic appearance but at the sacrifice of strength. For labourers the head should be left, as it widens the hand, preserves the transverse metacarpal ligament, and thus adds to the stability and strength.

Occasionally the metacarpal head tends to be pushed backwards and becomes unsightly. If it is removed and the remaining adjacent fingers are adducted the hand is weakened. This may be prevented by using the distal part of the phalanx as a bull graft.

A study of everyday uses of the fingers of people engaged in the lighter occupations, such as typists and other keyboard operators, etc., shows that the index and middle fingers are those most frequently employed.

It is false reasoning to believe that an amputation of the head of the first metacarpal or even the fifth metacarpal gives the hand a better cosmetic appearance. Amputations of the fingers and parts of fingers are not uncommon and people ignore them, but if there is any deformity for which concealment is attempted, more attention is drawn towards it.

The ring and little fingers, valuable to craftsmen and labourers, can be more readily sacrificed in those whose occupation requires delicate and precise movements.

Scoop action is an important function of the hand, both with the hand used singly and as a complement to the other hand. Loss of the middle or ring finger of either hand seriously interferes with its action as a scoop.

The index and middle fingers are far more sensitive than the ring and little fingers, and less powerful in gripping heavy tools. For a good grip it is essential to have strong digits which can press against the palm of the hand. The gripping surfaces should therefore be painless and, if possible, without scars.

In the case of the middle and ring fingers amputations at all levels distal to the first interphalangeal joint are satisfactory.

A long stump gives strength to the hand and prevents the adjacent fingers coming together. Contrary to what is taught, amputations through the first phalanx, the metacarpo-phalangeal joints, and the proximal interphalangeal joints do not leave stumps which are of value. Amputation proximal to the metacarpo-phalangeal joint is not to be encouraged, as there is a tendency for the remaining digits to be pulled together thus displacing the metacarpal shaft of the amputated digit backwards. In any case, by preserving the insertions of the interosseous and limb muscles, the power of the grip is left.

In the case of a manual worker with a flexion contracture of the index or little finger these fingers can remain out of the grasp if so desired.

Amputation of the ring finger and of the little finger weaken the leverage because they act as a fulcrum, e.g. in the case of a workman holding a spanner.

Lower Extremity

Hind-quarter Amputation

Before the beginning of the seventeenth century when Harvey discovered the circulation of the blood, apart from the morbid conditions which demanded amputation, hæmorrhage, shock and sepsis made it a dangerous procedure. As a result of Harvey's

discovery however much of the anxiety of hæmorrhage was eliminated by the more controlled methods surgeons were able to adopt, so that today apart from such contributory factors as age, general health or concomitant disease amputation is no longer regarded as a dangerous procedure. There is only one operation which gives rise to anxiety the interinnomino-abdominal operation It was not until 1895 that a successful result was obtained by Girard. Since that time the operation has been performed by many surgeons with increasing success, due to improved methods of resuscitation and control of hæmorrhage, together with increasing technical operative experience

Gordon-Taylor in 1946, reported a series of twenty-one personal cases, and since that time has performed a further eighty such operations. It is largely as a result of his work that this formidable ablation has been established, in this country as a standard procedure in the surgical management of malignant disease affecting the root of the limb where disarticulation of the hip joint would be inadequate.

On occasion the operation has been performed for extensive tuberculous or chronic inflammatory disease of the hip-joint and pelvic bones, but it should be remembered that a tilting-table is difficult to fit, and difficult and uncomfortable to wear

Description of the Operation

Position on the Table—Preliminary The patient is placed lying on his sound side, with a sandbag in the small of the back and another under the thigh on the sound side The upper arm is fixed on an arm-rest, while the lower is held on a board. The surgeon stands behind the patient. He should have three assistants. One holds the leg to be amputated, the second stands beside the surgeon, and the third by the side of the second.

Blood transfusion is started in the form of two intravenous drips This is important, as the patient may need a rapid massive transfusion. One transfusion can be started in the forearm of the unaffected side, and the other on the back of the forearm on the affected side.

A polythene catheter is introduced and tied into the urethra before the operation is commenced.

The leg should be exsanguinated by an Esmarch's bandage applied to the mid-thigh before the operation, and a piece of oiled silk is stitched over the anus to isolate this, so that it cannot contaminate the operative field.

The Operation First Stage. The incision employed is that designed by Girard.

(1) It begins at the symphysis pubis and extends across the iliac fossa to the anterior superior spine of the ilium. It continues downwards over the greater trochanter and across the gluteal fold, then upwards to its point of origin.

(2) The attachment of the rectus abdominis muscle is cut, and the inguinal ligament is divided at its attachments to the pubis and the anterior iliac spine

If any doubt exists as to the extent and fixation of the disease, in the case of a neoplasm, for instance, on the inner aspect of the innominate bone, both extent and fixation can readily be ascertained at this stage of the operation.

(3) The inferior epigastric vessels are ligated and divided, and the spermatic cord is retracted

(4) At this stage the iliac fossa and the retroperitoneal pelvic space are exposed by retracting the detached abdominal wall and peritoneum medially

In the case of a growth the tumour mass will be seen to fill the iliac fossa, and its whole extent can be investigated as far back as the sacro-iliac joint

The ureter should be carefully avoided it is generally adherent to the peritoneum and is reflected with it.

(5) It is important to expose the common iliac, external iliac and hypogastric arteries. A controlling tape is then placed round the common iliac artery which is occluded throughout the remainder of the operation. (It can be permanently ligated.)

(6) The external iliac artery is doubly ligated and divided. The symphysis pubis is well defined and divided with a chisel. The amount of bleeding at this stage is usually minimal

THE OPERATION SECOND STAGE

(1) The patient is then gently turned farther over on his sound side, and the posterior dissection is begun by cutting through the muscles attached to the iliac crest and the gluteal attachments to the posterior surface of the sacrum. The dorsum of the ilium and the sciatic notch are exposed.

(2) At this stage a Gigli saw is introduced underneath the sciatic notch and led through the notch from within the pelvis.

(3) The Gigli saw is then withdrawn by means of a strong pair of forceps on to the dorsum of the iliac bone.

(4) It is more expeditious, and produces less shock, to saw through at the site of the sciatic notch than to disarticulate at the sacro-iliac joint but if the extent of the tumour growth does not permit splitting the ilium at the sciatic notch, the much more difficult procedure of disarticulation at the sacro-iliac joint has to be undertaken.

(5) After the ligaments have been cut, an osteotome is introduced into the sacro-iliac joint, and the two surfaces are separated with a mallet.

(6) The gluteal and obturator vessels and nerves, the sciatic nerve, and the pyriformis and levator ani muscles are sectioned.

(7) The sacro-tuberous, sacro-spinous, and posterior sacro-iliac ligaments are then further severed.

(8) Returning to the anterior dissection, the psoas muscle, and femoral nerve are divided, while the external iliac vein is isolated and doubly ligated before it, too, is divided.

(9) It will now be seen that the extremity is almost free for removal and can be drawn away from the intact pelvic peritoneum by division of the anterior portion of the pubo-rectalis muscle which is inserted behind the pubes

(10) All small bleeding points are then caught up and the controlling tape in the common iliac artery is removed. Normal pulsation occurs in this artery in the hypogastric and in the stump of the external iliac artery The amount of hæmorrhage is again minimal This method of temporary occlusion of the common iliac artery provides excellent vascular control of the whole area and makes the operation a much safer procedure.

(11) The skin flaps are approximated after the peritoneum has been reinforced by suturing the remains of the gluteus maximus and levator ani muscles to the flank muscles and the rectus abdominis. Through and through interrupted silkworm sutures are used

The most important points in successfully conducting this operation are the following

(1) Spinal anæsthesia or one of the modern techniques eliminates some of the shock in this drastic operation which involves severing of the lumbo-sacral cord, the first and second sacral, and the obturator nerves.

(2) Adequate blood transfusion should be started at the beginning of the operation and carried on until the operation has been successfully completed and the blood pressure of the patient has again become stationary

(3) Hæmorrhage is made minimal by temporary occlusion of the common iliac artery which provides excellent vascular control This vessel can however be permanently ligatured with complete safety

(4) Sawing through the dorsum illi at the level of the sacro-iliac notch is a simple and expeditious method of dividing the bone, and eliminates the shock and trauma of disarticulation of the bone at the sacro-iliac joint.

(5) Gentle handling of the patient and of the tissues further eliminates shock.

(6) The danger of necrosis of the posterior skin flap incidental to common iliac artery ligation is avoided.

Amputation at the Hip-joint (Fig. 390)

Subtrochanteric Amputation. Disarticulation of the hip is not a common operation and is usually performed for malignant disease.

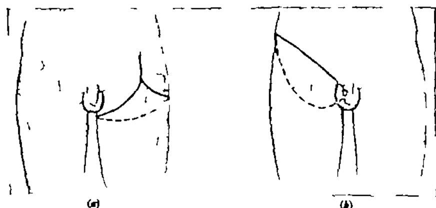


Fig. 390 (a) Racket incision for hip amputation and, (b) Fitzmaurice-Kelly incision for disarticulation of hip.

The most suitable flaps, except where surgically contra indicated, are unequal antero-posterior ones, the posterior flap being about four times longer than the anterior (Fitz maurice Kelly incision). It will be found when the final suturing is done, that the suture line falls in front and that the perimeters of the two flaps are almost identical

Incision. Small anterior flap midway between iliac crest and greater trochanter to 2 in below pelvic tubercle. Reflect to expose long saphenous which is divided and traced proximally to junction with femoral vein (superior branches of vein and artery being divided and ligated) Femoral vein is exposed and ligated by passing an aneurysm needle threaded with catgut and then divided between the ligatures. Medial and lateral circumflex iliac should be sought joining vein direct Artery divided between ligatures

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(9) It will now be seen that the extremity is almost free for removal and can be drawn away from the intact pelvic peritoneum by division of the anterior portion of the pubo-rectalis muscle which is inserted behind the pubes.

(10) All small bleeding points are then caught up and the controlling tape in the common iliac artery is removed Normal pulsation occurs in this artery in the hypogastric and in the stump of the external iliac artery The amount of hæmorrhage is again minimal. This method of temporary occlusion of the common iliac artery provides excellent vascular control of the whole area and makes the operation a much safer procedure.

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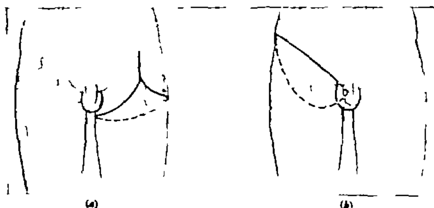


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Incision. Small anterior flap midway between iliac crest and greater trochanter to 2 in. below pelvic tubercle. Reflect to expose long saphenous which is divided and traced proximally to junction with femoral vein (superior branches of vein and artery being divided and ligated) Femoral vein is exposed and ligated by passing an aneurysm needle threaded with catgut and then divided between the ligatures Medial and lateral circumflex iliac should be sought joining vein direct Artery divided between ligatures

about 3 in. below inguinal ligament well exposed to profunda femoris which is ligated and divided. The circumflex femoral arteries arising from this are sought and divided.

The incision now carried round posterior aspect of thigh convex downwards and more generous. Soft tissues may now be divided down to bone without serious blood loss.

(1) An alternative racket incision can also be used as follows

(*a*) A vertical incision 3 in. long (7–5 cm.) is made from the inguinal ligament along the line of the femoral artery

(*b*) The incision is carried obliquely down the inner side of the thigh to a point 4 or 5 in (10–12 cm.) below the genito-femoral fold. It then extends across the back of the limb and up over the outer aspect, to meet the handle of the racket in the inguinal fold. The incision is made a little lower on the inner than on the outer side

(2) The anterior flap is dissected upwards towards the inguinal ligament

(3) The femoral vessels are dissected out, first the artery and then the vein, and doubly ligated and divided respectively

(4) The femoral nerve is divided without crushing it.

(5) The anterior femoral muscles are then divided preliminary to opening up the joint.

(6) The four adductor muscles, the sartorius, tensor fasciae femoris and the anterior femoral muscles are divided.

(7) The deep femoral, the external and internal circumflex arteries, and their branches are now caught up and divided. (During this part of the procedure any inguinal incision is a convex flap which starts at the medial end of the first incision and passes downwards convex inferiorly for about 6 in. (15 cm.) in the adult and 4 in. (10 cm.) in the child, to meet the first incision lateral to the anterior superior iliac spine)

(8) The flap is then dissected up towards the buttock, superficial to the deep fascia.

(9) The hamstring muscles, the glutei quadratus femoris, and ilio-psoas muscles are divided.

(10) The following vessels are caught up and divided the superior and inferior gluteal arteries, the first perforating branch of the profunda femoris and the internal saphenous vein.

(11) The sciatic nerve is divided, as well as the obturator and the external and posterior cutaneous nerves of the thigh.

(12) The capsular and teres ligaments are divided, thus allowing the lower extremity to be removed.

(13) After removing the lower extremity the large cavity is packed with a towel, and all bleeding points are carefully caught up and ligatured. The wound is drained and closed in layers.

Disarticulation at the Knee Joint. The operation of disarticulation at the knee joint is best performed with the patient lying prone

(1) In cutting the skin flaps, a generous amount of skin should be allowed, especially anteriorly A semilunar incision, commencing at the level of the joint laterally is carried downwards for about 2 in. below the popliteal fold. The flap includes skin and superficial fascia down to fat.

(2) The popliteal fossa is now entered and the popliteal artery and veins are doubly

ligated before division They should be ligated below the origin of the superior genicular branches. The popliteal nerve(s) are divided

(3) The muscles bounding the popliteal fossa are then divided including the popliteus muscle, the oblique popliteal ligament and the capsule.

The patient is then turned on his back and the operation is completed as follows

(4) A semilunar incision is made commencing at the level of the joints laterally and passing downwards for at least a handsbreadth below the patella, and below the tibial tubercle, and finishing at the joint level medially The ends of the anterior flap are made to join the ends of the posterior flap.

(5) The skin should not be dissected from the subcutaneous tissue, but these should be kept in a single layer in order to preserve the blood supply of the skin. The cuff of skin and fascia is dissected upwards until the ligamentum patellæ is reached.

(6) The ligamentum patellæ is then divided at the level of the knee joint. Thus the knee joint is entered.

(7) The knee is then flexed and the scalpel inserted between the femur and the semilunar cartilages, dividing the anterior parts of the capsule, coronary ligaments and synovium.

(8) The knee is then flexed to a right angle and the cruciate ligaments are divided.

(9) The remaining posterior portions of the capsule and synovium are then divided along with the collateral ligaments and the popliteus tendon.

(10) The remaining muscles bounding the popliteal fossa are then divided and the limb is freed and is removed

(11) The anterior flap is turned upwards and the patella carefully enucleated, the surrounding fatty tissues being preserved and approximated by catgut sutures

(12) If a condylectomy is desired, the femoral condyles are easily removed flush with the popliteal surface of the femur with an osteotome. At the same time the origins of the gastrocnemius muscle and plantaris can be removed. The fascia of the posterior flap is approximated by a few catgut sutures to the infrapatella tissues. The wound is sutured in layers without tension and the suture line should be behind the femoral condyles.

At the end of the operation there should be a good pad of tissue over the lower ends of the femur Drainage should be with a corrugated rubber drain, as these amputations are prone to form a hæmatoma. A Stokes-Gritti type amputation is less easily fitted with a prothesis than is a disarticulation of the knee.

Amputations Below the Knee. Before deciding on below knee amputation an X-ray examination should always be carried out, because it is unwise to preserve an arthritic knee in a below-knee stump which may ultimately prove functionally unsatisfactory

Syme's Operation (Disarticulation of the Foot at the Ankle Joint). The best descriptions of this hundred year-old procedure are given by the older writers Syme introduced his operation with this statement "It may be startling, but it is nevertheless true, that amputation at the ankle joint, with hardly any exceptions may and ought to supersede amputations below the knee." This statement may not be as true now as it was a century ago, but we should still stop and think before resorting to a below knee amputation. This is especially true of amputations in children.

Syme's original operation is to be preferred to the various modifications. Syme operated without a tourniquet. "An assistant," he said, "has complete command of the vessels by grasping the ankle. This is open to question. I recommend a tourniquet

unless the vessels in the limb are diseased and are likely to suffer from the trauma of the tourniquet, in which case it is unwise to perform a Syme's amputation.

Syme's original description, as quoted by Erichsen, does not correspond in detail with Sir D'Arcy Power's quotations from Syme's work. Both descriptions may be summed up as follows

The foot projects well over the end of the table The surgeon's left hand grasps the ankle. His thumb and forefinger mark the tips of the malleoli

(1) The point of the knife is entered just below the external malleolus. Taking a direction slightly backwards the incision crosses the sole to a point ½ in (1 25 cm.) below and behind the tip of the internal malleolus.

It is better at this stage not to divide the tissues behind the malleolus lest the posterior tibial artery be severed before giving off its terminal branches. Erichsen, however states that this precaution is quite unnecessary The inclination of the incision should be decidedly backwards. The common fault is to make too large a heel flap

(2) The heel flap is dissected from the plantar fascia and os calcis, keeping the edge of the knife in close contact with the bone

(3) The Tendo Achillis is divided or raised with the periosteum.

(4) With the foot in plantar flexion, the dorsal incision is now made. It joins the two ends of the incision for the heel flap The dorsal incision passes across the line of articulation, i.e about an ½ in. (1 25 cm.) above the tip of the internal malleolus. The ankle joint is opened while the foot is strongly plantar flexed

(5) The lateral ligaments are divided by working the knife downwards on each side between the malleoli and the astragalus.

(6) The foot is then removed.

If the lower ends of the tibia and fibula have escaped injury or disease, only the projecting points of the malleoli are removed with saw or bone forceps. The saw line must be kept strictly at right angles to the long axis of the leg when removal of the articular surfaces is part of the operation. The tendons are drawn down and cut short, and the nerves i.e. anterior tibial, and musculo-cutaneous, together with the plantar nerves, are gently treated in like manner The nerves must not be left longer than necessary

If preferred, the dorsal incision may be made first, the ankle joint opened, and the Tendo Achillis divided from the front.

Trans-metatarsal Amputation. Transverse amputation of the fore foot through all the metatarsals results in a surprisingly good walking foot, although the ease and efficiency of gait decrease progressively at each successively higher level of amputation. The tendency towards medial or lateral deviation is absent, because the balance of the foot is maintained. This is due to the preservation of the normal muscle attachments—tibialis anterior tibialis posterior and the peronei, whilst symmetry and shape of the stump are achieved, but equinus still tends to occur

This operation is again performed with the intention of obtaining a long plantar and short dorsal flap

The incision is placed on the dorsum of the foot, beginning at the midpoint on the inner aspect and passing convexly across the dorsum immediately distal to the anticipated bone level, to a similar point on the outer aspect of the fifth metatarsal. The plantar incision starts at the point of origin of the dorsal incision and is convex across the

plantar aspect of the foot at a level with the metatarsal heads It passes slightly upwards to unite with the lateral end of the first incision. In forming the plantar flap it should be remembered that the cross-section of the medial side of the stump is greater in depth than that of the lateral therefore the flap should be much longer on the inner side of the foot. A longer dorsal flap may be made if adequate plantar skin is not present, but the plantar skin should come up as far as the level of bone section on the inferior surface of the foot, since dorsal skin is not suitable for weight bearing. If sufficient plantar skin is not available then the metatarsal shafts must be made shorter The dorsal incision is now carried down to the bone, and the extensor tendons are divided and shortened so that they will retract above the edge of the wound The incision on the plantar surface of the foot is carried down to the bone, and the flexor tendons are severed and shortened The plantar skin, is dissected slightly above the level of bone section and a flap is formed consisting of plantar skin, subcutaneous fat, and a thin layer of plantar muscles. The intrinsic muscles of the foot are severed at the level of bone section. The metatarsal bones are now sectioned parallel to the tarso-metatarsal joints, and the fifth metatarsal is shortened and bevelled, all loose tags of periosteum being removed Nerves are not isolated they have all been sectioned and allowed to fall back in their beds above the line of bone section Hæmostasis is carefully secured. The skin flaps are approximated without tension, trimmed and closed with interrupted sutures. The skin on the sole of the foot, like that on the hand, is of a different texture from that of the dorsum It heals slowly so that the sutures should not be removed for about 2 weeks, and even then only alternate sutures until one is certain that union is taking place Not infrequently the skin edges are devitalized and will slough off leaving bone exposed. In this condition the wound should be left to granulate slowly and form a cicatrix which will be parallel to the site of amputation. Secondary suture should not be undertaken

Amputations of Toes

GENERAL CONSIDERATIONS

(1) The indications for amputation of the toes are similar to those for amputations of the fingers, with the addition that painful deformed toes are more frequently amputated than are deformed fingers. The big toe rarely requires amputation the fifth toe, how ever often does. Wherever possible, one should avoid amputating one or more inter vening toes as the remaining toes are pushed together and become clumped and painful It is good practice, if the big toe and one other toe require amputation, to amputate all the toes and make a dorsal scar Patients with all their toes amputated get about com fortably for 35–40 years, whilst partial amputations of the toes require periodic operations and amputations, and give the patient a great deal of trouble.

(2) The joint of the metatarso-phalangeal site is one of the important pivotal points on which the foot rests therefore, the great toe should never be amputated or dis-articulated except when absolutely essential. A single toe however even a great toe, should never be left, when the other four require removal, as there will undoubtedly be lateral displacement which is very troublesome.

The heads of the metatarsals should always be saved if at all possible

It should be remembered that the joint lies as far behind the web as the apex of the toe is in front of it, so that the incision should start farther back than might be at first expected.

TOE WITH AND WITHOUT REMOVAL OF THE METATARSAL BONE. As a rule it is not advisable to perform partial amputation of a toe, except of the great toe, but instead one should disarticulate at the metatarso-phalangeal joint otherwise the stump of the toe is only an inconvenience.

For the phalanges and interphalangeal joint the oblique circular incision is indicated, whilst for the metatarso-phalangeal joint a racket incision is made. The dorsal part of the incision extends down to the bone, which is removed subperiosteally

In the case of the great and little toe the dorsal portion of the incision is not placed over the middle of the phalanx and the metatarsal bone, but towards the middle line of the foot so that the cicatrix may be out of reach of lateral pressure.

The best results for removal of the Great Toe are obtained by Farabeuf's technique

"(1) An incision, starting from over the head of the first metatarsal, is made, extending down almost to the interphalangeal articulation it then crosses the plantar surface of the toe, extending to the web of the first and second toe the end of this incision is then carried back to the site of the commencing incision. (2) The incisions are deepened, the tendons divided, the joints opened and the toe removed. (3) The remaining internal flap is brought across the head of the metatarsal bone and leaves a neat cicatrix not exposed to pressure."

DISARTICULATION OF THE DISTAL PHALANX OF THE GREAT TOE. For a large plantar flap, hold the toe between the thumb and first two fingers of the left hand, the thumb on the pulp of the toe, the fingers on the nail. (1) Cut the plantar flap as the toe is thus held. (2) Enter the knife at right angles to the surface, just over the head of the proximal phalanx. (3) Cut along the side of the toe to the pulp

This incision should be parallel to the phalanx and nearer to the dorsal than the plantar aspect. (4) Shape the flap and return to the same point on the opposite side. The incision should extend down to the bone. (5) Forcibly flex the toe and make an incision across the dorsum by a transverse cut that at once divides the extensor tendon and opens the joint. (6) Rotate the toe out, divide the internal lateral ligament. (7) Rotate it in and divide the external band. Thus disarticulation is complete.

The long plantar flap should not be cut by transfixion. If the flap has been well cut, the two plantar digital arteries will not be wounded but will be buried in the flap until they anastomose at its free end. They may easily be cut accidentally if in dissecting the flap back, the knife is not kept close to the bone. They also lie near to the sides of the joint (plantar aspect) and may be easily wounded in careless disarticulation.

DISARTICULATION OF ALL THE TOES (METATARSO-PHALANGEAL DISARTICULATION) Each toe may be dealt with separately as follows

(1) The toe is dorsiflexed, and an incision is carried round it at the place where it emerges from the general cutaneous envelope of the foot. When complete, all the incisions are united at the webs on the plantar surface. The incision runs along the furrow between the digits and the ball of the toes. (2) Over the metatarso-phalangeal joint of the great and little toes a tarso-lateral incision is made. Thus two rectangular flaps are formed. (3) The toes are then bent towards the sole. (4) The extensor tendons are divided as far back as possible, the dorsal and plantar portions of the capsule together with the lateral ligaments are divided, and lastly the plantar tendons are cut across as high as possible.

This is an excellent operation and gives gratifying results for badly deformed toes.

AMPUTATION OR DISARTICULATION OF THE PHALANGES OF THE FOUR OUTER TOES In operating upon the smaller toes the neighbouring digits should be held aside by the assistant.

In disarticulation of the second phalanx use the oval or racket incision and proceed precisely as in the corresponding operation in the hand

OPERATIONS ON AMPUTATION STUMPS DESIGNED TO ENLIST RESIDUAL FUNCTION

These operations are usually in the upper extremity and they are designed to improve and to some extent compensate for the loss of a hand, e g. sensation and prehensile function

The special operative procedures may be listed as follows

(1) Amputation combined with arthrodesis of the shoulder (Gillis)
(2) Kineplastic surgery
(3) The Krukenberg "Forceps" Operation
(4) Neo-arthrosis of the Shaft of the Humerus (Gillis)

For a more detailed study of these, the original papers should be consulted.

(1) The indications for amputation combined with arthrodesis of the shoulder are a complete irrecoverable brachial plexus lesion in which the scapulo-thoracic muscles are still acting.

(2) The indications for kineplastic surgery are at present limited owing to the fact that there is no useful prosthesis available, but it has a place in congenital absence of the upper extremities in high amputations below the shoulder joint and in certain problem cases in which artificial limbs cannot satisfy the requirements of the patient

(3) The Krukenberg operation has a place in double forearm amputees who are blind, and also in certain specialized branches of employment.

(4) The loss of a forearm and hand where it is desired to utilize the remaining musculature of the arm by a method other than kineplastic surgery

(1) Amputation Combined with Arthrodesis of the Shoulder

It is well known that the results of repair of brachial plexus injuries are poor Fortunately in most cases, the scapular muscles retain their nerve supply and I have found that amputation combined with arthrodesis of the shoulder is of great value in this condition, when the scapula is mobile and functional.

The arm is amputated 6 or 7 in. below the acromion and at the same time an intra articular arthrodesis of the shoulder is performed, using as a graft a portion of the ulna from the amputated segment. The ideal position is about 40° of abduction at the shoulder

When healing is complete (approximately 6 months afterwards) the patients can then be supplied with an upper arm prosthesis which they can control by their remaining scapular muscles

(2) Kineplastic Surgery

From time to time surgeons have recognized that many muscles in an amputation stump are ineffective, and have sought means to harness their power in order to increase

function. *Kineplastic surgery* is the means whereby certain muscle groups are isolated and utilized to work certain modified prostheses.

There are three main types

(1) The clava or club motor
(2) The ansa or loop motor
(3) The canalis or tunnel motor

(1) **Club Motor** In this operation the tendinous insertions of muscles into bone, or the muscle expansions on to the bone are freed together with a portion of adjacent bone, and then covered with skin When the muscle contracts the bony nodule is moved, and by suitable mechanical devices can be made to move a prosthesis It is used mostly in above-elbow amputations



Fig. 391 Kineplastic tunnels in the flexor and extensor groups of arm.

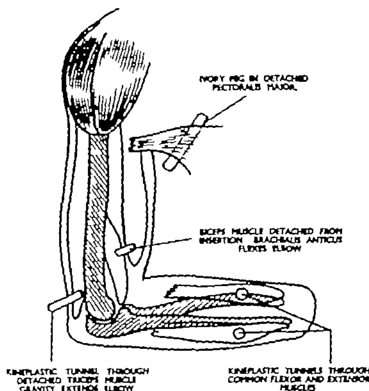


Fig. 392 Diagram showing the usual accepted sites for kineplastic tunnels.
(*Ann Roy Coll Surg Eng*)

(2) The Loop Motor This operation consists of forming a terminal loop of skin, muscle, and subcutaneous tissue at the end of a stump, together with shortening of the bone. It is only of interest.

(3) The Tunnel Motor This is perhaps, the only kineplastic operation likely ever to have a practical place in surgery A tunnel is made through the flexor and another through the extensor group of muscles, and lined with a tubed skin pedicle The tunnel thus formed can be connected up to work a light mechanical hand (see Figs. 391 and 392).

(3) The Krukenberg Operation

The object of this operation is to convert the radius and ulna into the two jaws of a crocodile forcep, thus enabling the patient to have a gripping and sensory stump without



Fig. 393 Bilateral Krukenberg "claw" writing.
(Ann. Roy. Coll. Surg. Eng.)

the need for a prosthesis. A V-shaped incision is made between the ulnar and radius on the flexor and extensor surfaces of the forearm, and deepened to divide the interosseous membrane for 10-12 cm The muscles are divided into a radial and an ulnar group and sutured, and skin closure effected if necessary by grafting. The operation, though thought unsightly by some seems to have a definite place in selected cases (see Fig. 393)

(4) Neo-arthrosis of the Shaft of the Humerus

This operation is of value in cases of amputation of the upper limb above the elbow joint. It involves constructing a simple joint in the shaft of the humerus at the site of election for amputation with a short distal stump that can be made to function as a forearm controlled by the powerful flexor and extensor muscles that control the natural forearm.

After much experimental work it is found that extra periosteal resection of 2 in. of shaft of the humerus at the site of the proposed joint, followed by diathermy of the bone

ends and packing the resultant cavity with sulphanilamide powder has been the most satisfactory way of ensuring non-union and false joint formation. A satisfactory range of movement at the new elbow joint has been achieved in several cases.

AMPUTATIONS IN CHILDREN

The indication for these are as follows

(1) Severe trauma accompanied by vascular and nerve destruction.
(2) Disease, e.g. malignancy osteomyelitis, etc.
(3) Congenital deformities.

(1) It is a cardinal principle in amputations in children that as much bone and soft tissue as possible should be preserved Wherever possible disarticulations are preferable to amputations.

(2) Since the introduction of antibiotics the necessity for amputation in diseases like tuberculosis and osteomylitis very rarely arises. The conditions usually requiring amputations are trauma, malignant disease, congenital deformities and, rarely residual deformities in poliomyelitis. For malignant disease it is a cardinal principle that a disarticulation well above the site of the disease is required.

(3) Surgery should not be resorted to until the avenues of orthopaedic correction have been explored, and then only when it is certain that the artificial limb which will be supplied will be an improvement. Short limbs can usually be accommodated in extension artificial limbs which conceal the deformity and at the same time compensate for the shortening. Amputation can always be resorted to at a later date when the growth of muscle and bone have reached their maximum and when the surgeon has a better idea as to what amputation can offer There are cases of congenital deformities and poliomyelitis that have worn calipers and high boots which after careful consideration benefit by an amputation but only when growth has ceased.

COMPLICATIONS OF STUMPS

Complications occur in stumps and are either associated with conditions which are inherent in the stump or are associated with faulty limbs or limb wearing.

Minor Skin Lesions

However minute and simple these are they are nevertheless of great importance because they may prevent a patient from wearing his artificial limb.

Furunculosis, folliculitis, heat rash, dermatitis, intertrigo, and eczema are all conditions which require not only treatment for the condition as such, but require prophylactic treatment and adjustment of the limbs because they may become incapacitating and eventually difficult to eradicate.

Post-traumatic Epidermoid Cysts

These post traumatic epidermoid cysts appear in the skin in the adductor region of the thigh along the line which corresponds to the upper rim of the socket in an above knee prosthesis. They occasionally occur also on the inner aspect below the knee in below knee amputations.

At first the cysts disappear or become quiescent when the artificial limb is not worn, but in time they increase in number and size and the skin may break down, become secondarily infected and discharge pus and result in chronic sinuses, which may track into the scrotum or vulva. The skin in the infected region frequently becomes lumpy indurated, and pigmented. At this stage, it is impossible for the patient to wear a prosthesis and he has either to take to crutches or remain in bed.

The pus which is obtained from a discharging sinus contains not only polymorphs but squamous epithelial cells. No single causal organism of infection has been identified.

The underlying cause of this condition is the piston action which is imposed on the stump by the badly-fitting socket of an artificial leg. Each time the weight is put on to the limb the stump is pushed into the socket and trauma occurs on the stump at the upper rim of the limb In these cases the pressure is unevenly distributed being mainly on the anterior and medial edge. This oft-repeated pressure and release causes some displacement of the skin. Epithelium is forced inwards into the corium. Bland-Sutton in 1891 and King in 1933 described similar cysts resulting from recurrent traumata elsewhere. This condition, previously described as that of sebaceous adenoma is in reality a form of post-traumatic epidermoid cysts.

Treatment These cysts are intractable and recurrent and cause much disablement among artifical limb wearers. (1) Abstain from limb wearing. (2) Adjust the socket and alter it to a more suitable type. (3) Paint with iodine (3 per cent) (4) Local injection of penicillin. (5) Express the infection and if necessary perform local curettage. Operation should be confined to local excision general dissection is not advised as it does not yield good results.

Ulcers of the Stump

Both acute and chronic ulcers are found at the ends of stumps.

(1) Acute Ulcers. These ulcers may be on healthy stumps and are caused, as elsewhere in the body by a repeated irritation such as trauma resulting from the artifical limb

Treatment (1) The amputee should abstain from using his artificial limb, which should later be adjusted. (2) Local application and appropriate antibiotics will clear the ulcer

(2) Chronic Ulcers. Most chronic ulcers occur at the end of the stump and are a great source of incapacity to the amputee. They are found mostly in below knee stumps.

The following are the types of chronic ulcers seen

(*a*) Douglas of Roehampton made a study of the pathology of these traumatic ulcers which remain unhealed in spite of all methods of conservative treatment. Normally the mobile subcutaneous tissue containing blood-vessels, nerves, and sweat glands allows the dermis or true skin, with its epidermis to move freely over the underlying muscle or bone beneath it, and is separated by the deep fascia.

In the case of an amputation, the cut end of the muscle is now no longer surrounded with its sheath of connective tissue. If there is insufficient fascia to cover the cut end, the muscle becomes attached to the scar (microscopically the muscle fibres can be seen embedded in the firm connective tissue years after the original amputation), an ulcer may develop the scar being drawn up by muscular movement. If the skin also breaks over the end of a bone and exposes the periosteum, healing takes place from the floor of the

wound, and the firm fibrous tissue fixes the ulcer to the bone. The subcutaneous tissue is obliterated by fibrous tissue thus interfering with the blood supply and producing a state which is unfavourable to the healing of the ulcer

Treatment To eradicate this ulcer satisfactorily and to make the stump fit for limb wearing the surgeon should bear in mind the pathological condition. It is necessary to re amputate. Merely to excise the ulcer is to invite further pathological complication. Bone and fibrous tissue must be liberally excised, and then the fascia and skin approximated as in a primary amputation. Success in these stump revisions always depends on the presence of sufficient skin and the exclusions of muscle fibres from the resultant scar

(*b*) Chronic Pyogenic Ulcers. Infection of an amputation stump with pyogenic organisms is a frequent complication. Chronic pyogenic infection with ulceration may occur when the stump edges have not been satisfactorily approximated by sutures which have been placed under tension, and by inversion of the skin. If treatment of acute traumatic ulcers is neglected and limb wearing is continued, these ulcers become chronic. In this type of ulcer with its pale and scanty granulations, the floor becomes indurated and the skin area around pigmented. These ulcers are usually superficial and, unlike those described above, are not adherent to bone or muscle

Treatment (1) Abstain from limb-wearing. (2) Control the infection by appropriate chemotherapy or antibiotics. (3) Ultra-violet light therapy

(*c*) Ulcers following venous congestion of the stump Ulceration of the skin may occur when there is venous congestion or circulatory disturbances, due either to unsatisfactory limb fitting or vascular disease of the stump, similar to the condition for which the limb may have been amputated.

Tumours of the Skin

(1) Hyperkeratosis. This is a condition in which the skin of the stump becomes thickened, irregular and rough. It usually occurs at the end of the stump in deep and invaginated scars where the stump is subjected to a certain amount of pressure It becomes painful.

Treatment Refrain from limb-wearing, soften the skin with Zinc Oxide and Castor Oil ointment and then excise the hyperkeratotic area together with the neighbouring infolded scar and improve the cosmetic state of the stump

(2) Simple Papillomata. These may be found at the end of the stump Corns and callosities result from unequal distribution of weight over the surface of the stump, or weight bearing over unsuitable sites on the skin of the stump. Sometimes projecting growths assume large dimensions. These large papillomatous growths occur at the end of a stump. They are composed of many layers of squamous epithelium. The superficial layers undergo excessive keratinization. They never invade the deeper structure and are harmless so long as the germinal layer of the epidermis remains intact.

Treatment Re-amputation.

(3) Squamous Cell Carcinoma. These malignant growths supervene in old scars and in indolent ulcers of the stump in connection with sinuses. Papillomata may also become malignant.

Treatment Re amputation with resection of the regional lymph nodes, if they are involved.

Redundant and Adherent Folds of Skin

In some instances the socket of an above-knee amputation becomes too small. As the stump is pushed into the socket and the body-weight is supported by it, the skin is pushed up on the inner side of the socket. This site is one of the first areas where the integument comes into contact with the socket. The result is that this area of skin and subcutaneous tissue does not enter the socket. It is now subjected to the plunging movements of walking and hangs over the rim of the socket.

At first the formation of a roll of tissue is temporary and disappears soon after the removal of the constricting socket. Soon, however, fibrosis takes place at the base of the roll of tissue owing to repeated minor trauma, and the roll of subcutaneous tissue becomes permanent. It forms an overlapping mass which can now readily be nipped between the adductor tendons and the trumpet-shaped mouth of the socket. These rolls of tissue occur with sockets which are too tight, owing to the fact that the stump has hypertrophied. On the other hand, they may form during the shrinking phase of the stump. In such cases the loose skin and subcutaneous tissue is displaced outside the socket by the piston action. To attempt to diminish the size of such a socket by lining it will only increase the effect.

Frequently this condition occurs in older amputation cases, particularly those which have been amputated for 10–15 years. A "roll of tissue" may develop on stumps which for a number of years have been satisfactory. This roll of tissue remains out of the socket permanently and is subjected to the trauma of the socket. It becomes pendulous and painful and septic epidermoid cysts develop in it.

Treatment. The treatment consists of inspection of sockets at regular intervals and the prescribing of a more suitable shape and size of socket for the particular stump.

Lesions of Blood Vessels

(1) Hæmatoma. Hæmatoma formation in a stump that would otherwise heal by primary intention is a tragedy. Quite often the limb has to be amputated because of gangrene or chronic osteomyelitis following a compound fracture. Where there has been a great deal of skin infection œdema occurs. The tissues around the amputation area are heavily infected with bacteria, because the lymphatics and veins of the diseased area must of necessity drain through the proximal operative site. A hæmatoma in such a site becomes an admirable culture medium. The avoidance of hæmatoma is, therefore, a primary consideration. Strict attention should be paid to hæmostasis, and aseptic technique. In all these cases one should administer wherever possible, the appropriate antibiotic prophylactically and during the stage of healing. Should a hæmatoma occur this can be aspirated under aseptic conditions, and the best site is usually opposite the suture line, in the line of the hæmatoma. A wide-bore needle is the best for aspiration. Repeated aspirations may be necessary. The stump very often oozes blood and serum for weeks afterwards, and finally an incision may have to be made to evacuate the clot.

(2) Calcified Hæmatoma. This is an uncommon complication and occurs on the side of the stump. It may follow an injury and becomes aggravated by wearing an artificial limb too soon afterwards. The hæmatoma forms and organization takes place at the periphery with deposition of calcium. The centre of the hæmatoma undergoes

liquefaction, followed by calcifaction the patient complains of some discomfort and is unable to wear the limb. Radiograms show a calcified swelling is present.

(3) **Chronic Venous Congestion of Stump (Choked Stump).** Stumps may be the site of chronic venous congestion. This condition follows excessive scarring of the stump excessively long stumps (especially in the lower third of the leg or forearm) and cases which have been amputated because of peripheral vascular disease. Sometimes an inaccurately-fitting socket causes oedema. This can, however be overcome by removing the constriction in the socket or correcting the defect in the prosthesis, e.g. (1) tight socket, (2) suction limb The stump is cold and cyanotic The skin at times is blanched and breaks down, forming an ulcer This complication is frequently accompanied by intractable pain and may require re-amputation.

Treatment

(1) Refrain from using a prosthesis until the symptoms have settled down and the cause adjusted.

(2) Adjustment to the socket for size and alignment.

(3) Rest and elevation of the limb

(4) Supportive bandage

(5) Local treatment of ulcer

(6) If these measures fail, re-amputation at a higher level.

Bone Lesions

Periostitis. Periostitis of the bone is not uncommon. It occurs at the cut end of the bone Large proliferated, thick masses of bone develop and extend along the shaft about 2 in. (5 cm.) from the cut end When the infective processes subside, thickening remains as evidence of chronic osteomyelitis. Infection at the time of amputation may give rise to this condition At times masses of new bone are found in the soft parts of the stump Infection usually stimulates the osteogenetic layer of the periosteum to proliferate, and the base of the stump resembles the large irregular stem of a tree, with a cauliflower shaped end.

Sequestrum Formation. Ring-shaped sequestra are found at the base of the stump (*see* Fig. 394) The open medullary cavity becomes infected and the resultant osteomyelitis spreads for a variable distance up the shaft of the stump. The cortex gradually becomes necrosed and slowly separates from the shaft. A small portion of the whole circumference may be the initial site of the condition which gives rise to a sequestrum. The layers of the bone may continue to necrose and form a ring of sequestrum. The medullary cavity becomes obliterated by the formation of new bone, which cuts it off from the site of infection. When the sequestrum is removed it has a clean-cut distal end, where it had been sawn through, and a short or long tapering proximal end which is irregular with tapering spikes, where it has separated from the living bone of the stump

Sinuses

These occur at the end of the stump, occasionally higher up. Button-like areas of granulation tissue form round the mouth of the track. At the end of the stump they may be associated with a sequestrum, a retained foreign body such as a swab, a metallic foreign body and often a ligature. If the sinus does not clear up in 4 weeks after an

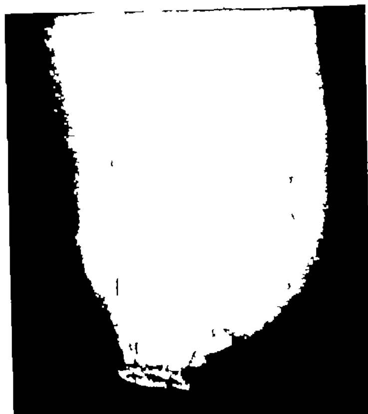


FIG. 394 Complex bony spurs on lower end of tibia and fibula There is typical ring sequestrum separated from the lower end of the tibial stump.

amputation and there is no obvious X-ray evidence of the cause, it requires curetting (*see* Fig. 395) under antibiotic cover The removal of a stitch in the depths of the wound allows it to close rapidly Sequestra and foreign bodies should be removed by excising the whole epithelialized track together with the offending foreign body At the same time all excess fibrous tissue should be removed. Not uncommonly a sinus may have been discharging for some time and this chronic discharge infects the skin and causes an eczematous condition. This is a very incapacitating lesion, obstinate to cure and prevents the patient from limb-wearing for months. The sinus should be dealt with as soon as possible and the eczematous skin is best treated with ultra violet light. Occasionally this local eczema gives rise to a generalized eczema of the body caused by the absorption of toxins. The patient loses his appetite and becomes febrile, and after varying periods of illness, exfoliation occurs. Ultra-violet light to the whole body has proved of value together with the administration of vitamins.

Nerve Lesions

After division, there is Wallerian degeneration, followed by proliferation of the axis cylinders. After a few months a bulbous mass is formed consisting of axis cylinders

fibrous tissue, the motor fibres being useless, and the sensory fibres continuing to transmit impulses, so that excitation gives the sensation of some part of the periphery being touched or stimulated. It is normal for the amputee to experience a sensation of numbness and even pain related to the amputated limb. There may be local pain or soreness from repeated friction, in reality bruising of the nerve bulb



Fig. 395 Short above-knee amputation. Multiple foreign bodies present. The bullet fragment later caused trouble and had to be removed

A distinction should be made between a tender and a painful stump. A tender stump is painful on pressure only while a painful stump is one in which the pain is aggravated by palpation or the wearing of a limb and there is pain even when there is nothing in contact with the stump There are two types of tender stump one is due to a hyper sensitive neuroma (Fig. 396) and the tenderness is local the other the pathology of which is still obscure, can be aggravated by pressure and the tenderness is general.

Generally speaking tenderness disappears about 2 months after amputation, providing that the precautions of not traumatizing the nerve have been carried out.

When the tenderness persists the wound has generally not healed by first intention and sepsis has ensued. *It is essential in diagnosing these cases to* establish whether the pain is present without limb wearing or if it is aggravated by limb wearing. Pain which is aggravated by limb wearing may be improved by adjustments of the sockets or the alignment of artificial limbs. When the limb is worn, traction is exerted by piston action which may drag the skin on the deeper structures or by the pull of muscles on the neuroma which is also fixed to the skin and immobilized by the socket.

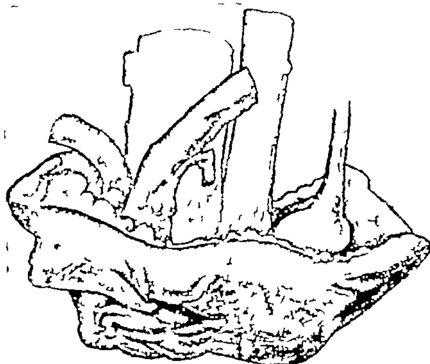


FIG. 396. Amputated stump segment showing neuromata attached to base of ulcer

All patients with painful stumps should be treated seriously and the surgeon should make absolutely certain that the artificial limb is satisfactory. The pain may be present in the stump itself and due to the recurrence of inflammation in the soft tissue or in the bone. Limb wearing should be discontinued and the inflammation treated.

Referred Pain

Pain may be referred from disease elsewhere, e.g. anginal pain may be referred to an arm stump, or nerve root irritation of a lumbar root may cause symptoms in a leg stump or even phantom pains.

Clonic Spasm

In a few amputation stumps clonic spasm occurs. The patient is unable to prevent his stump from jerking up and down. The jactitation may be associated with local

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and mentally so that he can use the amputated stump and his artificial limb to the utmost value.

(1) Preparation of the Stump

Immediately following amputation, all stumps are œdematous bulky and the shape requires remodelling from a cylinder to a cone. The soft tissues begin to shrink and it is desirable to obtain the maximum shrinkage as soon as possible so that measurements may be taken for an artificial limb, in order to get the most accurate fit for the socket.

The conversion of a large cylindrical stump into a small conical stump is achieved by continuous lateral compression in such a way that the maximum force operates at the lower end of the stump and diminishes in an upward direction. This can be achieved by

(*a*) elastic stump socks,
(*b*) by the wearing of a plaster pylon,
(*c*) the application of a crepe bandage to the stump

(*a*) **Elastic Stump Socks.** This is a useful method for modelling amputation stumps. A conical well-healed stump can result by this method which has now superseded method (*c*) stump bandaging.

These elastic stump socks are made from two-way stretch material, specially woven to give maximum pressure at the distal end of the stump

The advantages of these elastic socks are

(1) They exert an even pressure and so reduce the œdema.

(2) They do not produce folds and invaginate the skin, thus leaving furrows.

(3) They shape the stump in a conical manner and produce an even contour leaving a linear scar

(4) The patient can apply and adjust the socks himself

(5) They are not cumbersome, require no bandaging and save the time of the physiotherapist.

(6) They do not, however preclude the patient or the physiotherapist from carrying out stump exercises.

(7) They are valuable particularly in cases of amputation for vascular disease as the even pressure does not produce skin abrasions and trauma.

These stump socks are made in two types, one set for above-knee amputations and another set for below-knee amputations. They are made in three graded sizes—small, medium, and large.

The small below knee socks are also suitable for arms.

They are easily washable, are economical, and can be used by the patient at night as well as by day They last for at least 18 months.

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(6) It is easily and quickly made and can be available in 2–3 hours.

(7) It enables the patient to become ambulatory as soon as his stump has healed.

irritation such as sepsis or there may be no apparent cause, in which case sedatives and physiotherapy can be given, often with good effect.

Painful Phantom

All amputation patients are conscious of their lost extremities. The majority say that their sensations are not painful and that they gradually fade from consciousness. If a patient complains of these pains he should be reassured and it should be explained to him that this condition is not abnormal. He should be encouraged to try to forget the pain by diversions. Painful phantoms are more common in arm amputees than in leg amputees. The treatment, as a rule should be by placebos and surgical operations, e.g. root section should be avoided.

Conical Stump

In an amputation in a child the bone usually grows at a faster rate than the soft tissues and soon extrudes itself through the skin producing what is termed as a conical stump Most of the long bones present this problem, especially the humerus and the tibia, and the fibula, which grow from their proximal ends.

At the primary amputation it should be ensured that sufficient skin and soft tissue are available to cover the end of the bone. If there is sufficient length of bone an epiphysiodesis should be performed. This operation will prevent the child from having re-amputations.

POST OPERATIVE TREATMENT OF STUMPS

The stump should be rested until the wound has healed. The patient can then be sat out of bed from about the third day for increasing periods of time.

On the day after the operation the drain is removed if the wound is dry If blood is still running away the drain can be left for another 24 hours. When it is obvious that there is a large hæmatoma the surgeon should evacuate the hæmatoma in the theatre, by re-opening the wound, and tie the bleeding points. There may be no apparent hæmatoma, and very little blood flows out when the drain is removed yet a small hæmatoma exists by the time the stitches are removed. As a precaution, therefore, it is wise to inspect the wound and if a hæmatoma is present, a sinus forceps should be inserted through the suture line between two or three stitches which are removed and blood serum can then be expressed—it is usually under tension.

The stump should lie flat on the bed, and pillows which may flex the hip or knee are forbidden. The muscles controlling the joint immediately above the amputation are exercised to assist healing by improving the blood supply and to prevent stiff joints.

When stitches are removed the patient is encouraged to move his joints this helps to prevent the muscles becoming adherent to the skin, and improves the circulation. Above knee stumps, particularly if short, tend to develop flexion deformities at the hip since the flexors are relatively stronger than the extensors. In order to counteract this the patient should lie for a period of each day on his front, and in this position practice lifting the stump off the bed.

The surgeon's task continues after the amputation—his object should be (1) to prepare the stump for fitting with an artificial limb (2) to prepare his patient physically

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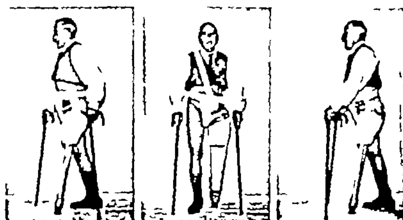


FIG. 397 Left above-knee pylon—hospital constructed. Walking with sticks. Note alternating position of walking sticks.
(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co., London.)

(2) Preparation of the Patient

There are two methods of using an above knee limb firstly the patient can swing the limb by means of his trunk muscles, in the same way as a patient with a tilting-table limb his gait then being ungainly or secondly the correct way control his limb by his stump muscles, his gait then being more nearly natural.

The majority of amputees should be trained to have stump-controlled limbs, but they cannot be expected to use them to the best advantage unless their stump muscles are developed and they have learnt to make use of those muscles so that the hip joint moves freely

The essential muscles are the extensors and adductors and flexors of the hip The patient should be encouraged to contract these muscles voluntarily as soon as he can after the amputation, and when the wound is healed he is sent to join classes in the gymnasium to exercise his stump.

An excellent exerciser can be made by horizontally fixing a piece of wood as long as need be to the wall at a height of 3 ft. from the ground (*see* Fig. 398). At intervals of about 3 ft., pulleys are screwed to the board. A webbing sleeve, 4 in. deep behind and 2 in. in front is passed round the stump. A cord passes from the sleeve over a pulley to a 7-lb. sandbag. The weight of the sandbag can be increased daily to 21 lb A movable handrail is placed a few feet from the wall. The patient faces the wall and rests his hands on the rail while he raises the sandbag off the floor by contracting his hip extensors. After a few minutes the sleeve is moved round the thigh and the patient stands sideways with the sleeve nearest the wall and again raises the sandbag off the floor this time by using the adductors of the hip The same exercise is repeated for the flexors of the hip

The work is gradually intensified by increasing the speed and duration of the exercises. Several patients are exercised at the same time, comradeship and the spirit of competition helping to improve not only their physical but also their mental well being.

The exercises are supervised by a physiotherapist who ensures that the patients keep their trunks still and do the work with their hip muscles.

Stump exercises serve three functions (1) the muscles regain their power (2) the brain re-establishes its control over muscles that have been in danger of being disregarded as of no further use and (3) a good range of movement is rapidly restored to the joints.

During the healing of the wound an above-knee stump may acquire a flexion adduction deformity This is made apparent if the patient lies on his front and clasps

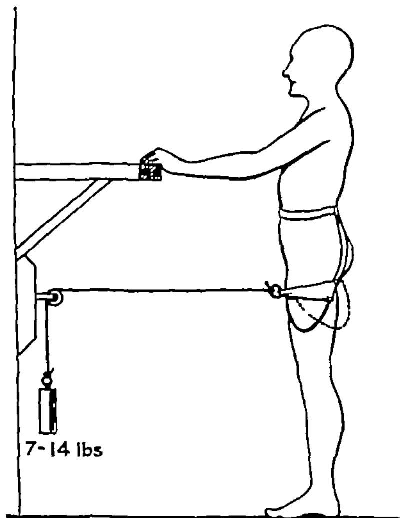


Fig. 394 Simple technique for developing stump muscles in gymnasium.
(A J Craft, Ann. Roy Coll. Surg. Eng)

his hands behind his head, and while in this position he raises his head shoulders, and elbows off the couch, the muscles of both hips contract by synergic action during this movement.

During the course of stump exercises the flexion abduction deformity diminishes. The exercises are continued daily until the stump no longer flexes or abducts during the test. Not until then is the patient considered ready to control an artificial limb.

The whole treatment—strengthening the muscles, re-educating them, and regaining mobility at the hip—takes on an average only 2 or 3 weeks.

For below knee amputations the quadriceps muscle alone requires strengthening and re-educating. This is done by getting the patient to raise the leg off the couch, with the knee straight, against resistance, quadriceps drill, and faradism.

In an amputation of the upper limb it is of the utmost importance to obtain the fullest possible movement at the shoulder joint and no patient should be referred for limb-fitting until he has regained full mobility of the shoulder muscles.

(3a) Teaching the Patient to Use an Artificial Leg

In the course of the manufacture of a limb the patient receives several fittings during which he uses his limb It is important that he should use the limb correctly from the beginning and one must rely on the limb-fitter to teach the patient the correct method. The surgeon cannot himself superintend the instructions, but he should be in a position to know what are the correct requirements as limb-fitters cannot be expected to acquire this knowledge without tuition. Before attempting to walk the patient is taught three things (1) to stand and to balance on the limb (2) to swing the limb forward without abducting it and (3) to extend the artificial knee at the end of the forward swing naturally

To Balance on the Limb A normal person when standing on one leg maintains his balance by using his foot muscles. A patient with an artificial limb has to rely on the muscles of his proximal joints which have to learn this new function. The patient stands in front of a mirror and balances himself on side rails. After a few attempts he is able to take his sound leg off the ground, then to do so without holding the rails, and finally he accomplishes this with the sound knee and hip fully flexed and the foot well clear of the ground.

He should then learn to swing the limb forward without abducting it. The tendency to abduction is less when the adductors have previously been developed the patient being required to learn to contract his adductors during the forward swing of the limb Walking should not be attempted until the patient can swing his limb forward without abducting it, for the ungainly circumduction gait, once acquired, is difficult to eradicate.

Whereas a normal person extends his knee by his quadriceps a limb-wearer must learn to extend the artificial knee by using his hip extensors and to control it at the end of the swing by pressing his stump backwards in the socket. At the completion of the forward swing he is therefore taught to place the heel on the ground and to press backwards with his stump muscles simultaneously

Having learnt these three lessons the patient may start walking. He is given two sticks and told to take short, equal steps with both legs. The two legs should be used evenly Any sign of a limp is immediately checked. The patient on reaching this stage soon accustoms himself to his limb, and learns to walk on uneven ground, on cambered surfaces, and up and down hill. On going upstairs he takes one step at a time, the sound leg leading. On going downstairs the artificial leg goes first and the patient must remember to keep the artificial knee extended. This is rendered easier by his leaning slightly forward over the limb

The learner is not allowed to look down at his feet as he walks, and must rely on his hip muscles for a sense of position.

(3b) Teaching the Patient to Use an Artificial Arm

Like leg amputees all arm amputees should be taught for several weeks in the company of other arm amputees. Observing how much can be done by others who have received their arms a week or two earlier is a great incentive. The stay in hospital enables the surgeon to supply those appliances most useful to an arm amputee most suitable to his mentality and trade As more and more dexterity is acquired the arm amputee becomes keener on doing more with the appliance he has, and on learning to make use of new ones.

ARM PROSTHESES AND APPLIANCES IN INDUSTRY

Artificial limbs are constructed to the individual requirements of the patient, and the actual construction varies with the different lengths of stump

In modern industry the loss of an arm must be prevented from making the amputee a liability and the advances made in artificial limbs over two world wars have shown that such men can be definite assets in industry and can also encourage self respect and confidence in the maimed.

The first necessity is that the patient s occupation must be studied with a view to providing an appliance which is compatible with the tools of his trade. It is also essential suitably to encourage the patient and to persuade him when he is fitted that the artificial limb is an asset to the super-educated remaining limb and not merely a useless appendage.

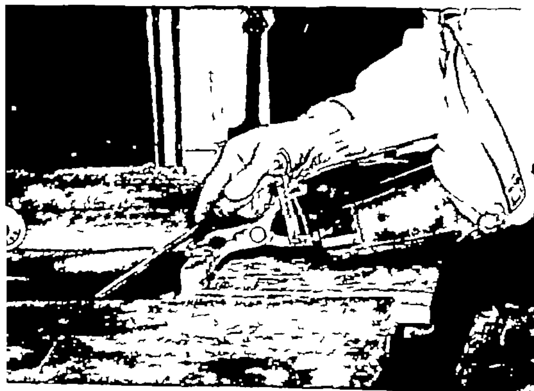


FIG 399 Some appliances used in bench work.
(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co., London)

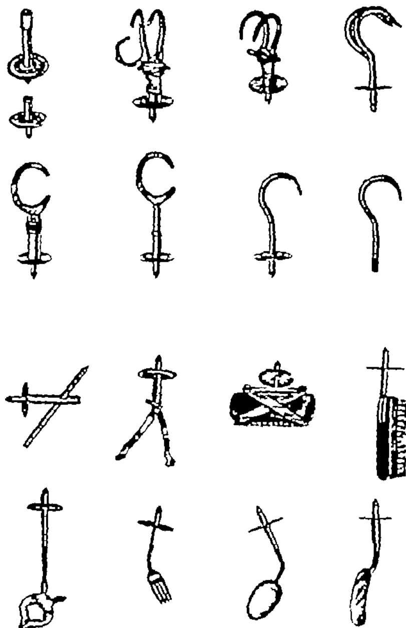


FIG 400 *Top* selection of tools which can be plugged into forearm rotary mechanism as required *Bottom* selection of household appliances which can be plugged in.

(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co London)

The artificial limb must be provided with an eye not only to its intended use but also with regard to the patient's anatomical configuration and to the physical strength of the stump and auxiliary muscles

Several types of arm are available from the light dress arm (suitable for women and light clerical work) to the heavy duty arm which will enable the wearer to perform quite heavy manual labour Numerous varieties of end attachments are available (*see* Figs. 399 and 400).

(1) Arm Prosthesis

These consist of a socket for the stump and a webbing and leather harness which suspends the arm from the body The shoulder muscles activate the end appliance via the harness. Joints can be attached at any level

The attachments vary for above and below elbow amputations The harness always passes across the back to the opposite shoulder and the chest is always left free.

For working arms it is an advantage to have a bisected forearm

Types of Prosthesis (Fig. 401)

(*a*) For long above-elbow amputations.

This type of arm is prescribed for long stumps when there is insufficient room for an internal elbow mechanism, which will enable both elbows to be symmetrical. It is possible to lower the elbow dome to allow an elbow mechanism to be inserted, but this makes the lengths of the upper arms uneven and it is impossible to lean the elbows on a table or chair and stay symmetrical It is a simplified type of working arm with external side joints fitted with a hand-operated locking mechanism. Flexion of the forearm is controlled by the leather shoulder thongs. For working purposes it is made of metal or leather or of both, and the forearm is of metal bisected with a rotary sector in the upper portion. The lower portion and hand are detachable Any appliance required for a special task can be securely locked into position in a moment.

(*b*) For above-elbow amputations with ideal length stumps.

The appliance for use with this type of amputation consists of a leather or metal socket designed for any class of heavy work. Within the lower one third of the socket is a totally enclosed elbow mechanism and semi automatic elbow lock. This gives good clearance and free action when using appliances which can be attached close to the elbow thereby giving the wearer greater control in their use The forearm and hand are intended for dress purposes only but the wrist is provided with rotary movement.

(*c*) Through-elbow amputations

The apparatus for use following this amputation is a blocked leather socket moulded to conform to the configuration of the arm stump The socket has an external elbow-joint mechanism between it and the forearm piece. Owing to the length of the stump it is not possible to provide any mechanism controlling elbow movement within the artificial arm itself The joint controlling the movement of the forearm is therefore, fitted externally A patent rotary sector in the upper portion allows the hand to be detached from the arm. Any of the many special attachments can now be replaced and used as required. To overcome the loss of the natural elbow it may be possible to construct surgically a new elbow joint in the shaft of the humerus, for example, neoarthrosis of the shaft of the humerus

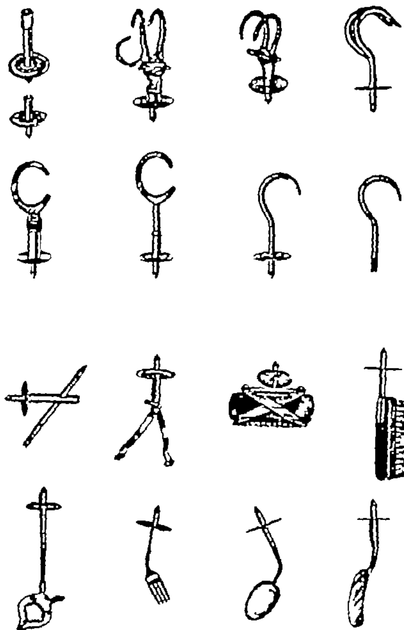


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(*d*) Below-elbow amputation apparatus.

This appliance for short below-elbow amputations consists of a moulded leather inner cup-socket. It is very necessary in short forearm amputations or in congenital deformities and is attached through the medium of external artificial elbow joints to the

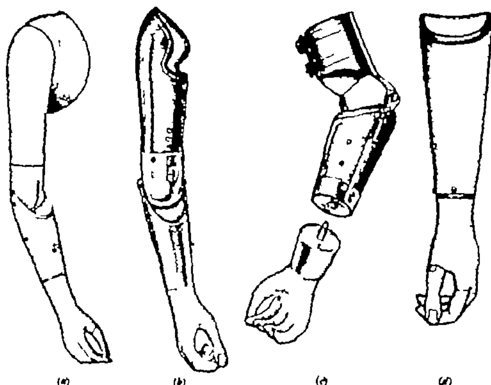


FIG 401 (*a*) Dress Arm for disarticulation at the shoulder This arm has forward and outward movement at the shoulder joint and, like the full working arm, has a natural line and appearance. Its weight is reduced to a minimum. An oval wrist can be fitted if the wearer prefers the bisection in the forearm

(*b*) Heavy and light working arm for an above-elbow amputation This is a useful and practical working arm with a fully automatic elbow lock which enables the wearer to flex and lock the arm automatically in several positions without using his sound hand The forearm can be semi-rotated from the elbow on lateral plane to give greater outward reach or to allow it to rest closer to the body and the rotary sector enables the hand or appliances to be rotated in either direction and kept there by a locking device.

(*c*) Working arm for a below-elbow amputation—short stump. The moulded inner cup socket of this arm gives maximum comfort and support The lower section of the forearm can be detached so that working appliances can be brought nearer to the distal end of the stump

(*d*) Dress arm for a below-elbow amputation The arm is fitted with a Sheplon socket without reinforcing steels It has a pleasing appearance and a hand with articulated fingers.

(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co London)

adjustable leather upper arm corset The artificial joints synchronize with the natural elbow joint but pronation and supination is not possible.

The bisected detachable hand can be plugged into the standardized rotary piece which is able to accept any of the devices described.

(*e*) Through wrist amputations.

The working arm for a through-wrist amputation is designed to suit the amputation, i.e. the exceptionally long forearm stump, where there is insufficient room to insert a

patent rotary sector Pronation and supination while wearing the prosthesis is not possible, and from a limb-fitting point of view this is considered a bad amputation because the bulbous stump formed by the expanded distal end of the radius makes the fitting of the prosthesis difficult. Further it adds little to its use, because the stump itself is of no great value as a proprioceptor and any prosthesis makes the limb on the stump side longer than the other side asymmetry being a hindrance

It consists of an adjustable leather socket with a metal cuff The socket is adjustable to allow the bulbous end of the stump to pass in easily and so obtain a good fit. The metal cuff is made so as to include a patent rotary wrist sector from which the hand can be detached and any of the many special purpose appliances plugged in for use.

(*f*) Appliances for partial amputation of the hands and fingers.

Numerous appliances are available for partial amputations of the hand. These take the form of a leather harness laced round the remainder of the hand with an attachment which takes the place of the lost members.

(*g*) Mechanical hands.

Mechanical hands are suitable only in cases where the elbow joint is intact or where a neoarthrosis is present. They are not generally suitable for heavy work.

(1) Positive control, when the hand is opened by cables worked by any single group of muscles. This type can be made to use fingers independently

(2) Negative control in which the hand is held open by a group of muscles against a spring which tends to close the hand.

(*h*) Dress arms and hands are made of light plastic and are useful only cosmetically for very light duties.

(2) Appliances for Arms

There are numerous types of hooks, blades, and other instruments which may be selected according to need. These can all be quickly plugged into or removed from the prosthesis.

Special training by an instructor who is also an amputee is essential and centres of this sort are provided. The amputee must persevere and be encouraged to use his artificial limb and to perform all his normal duties and be should also attempt to use the stump before the prosthesis is fitted.

ARTIFICIAL LIMBS FOR LOWER EXTREMITY

Through-hip Amputation

The most suitable type of limb for this amputation is of light metal and usually comprises a metal or other type of socket which completely encloses the stump, a hip joint which is made to lock automatically the usual type of thigh piece, ball-bearing knee joint, shin and wood foot with an articulated ankle.

There are various types of body suspension for this limb, the principal ones being a waistbelt or shoulder brace.

Amputation Above the Knee

Light metal or willow legs are suitable, the light metal leg having the advantage of being lighter The limbmaker is also able to fit various forms of frictional knee device which are not possible with the wooden leg.

(*d*) Below-elbow amputation apparatus.

This appliance for short below-elbow amputations consists of a moulded leather inner cup-socket. It is very necessary in short forearm amputations or in congenital deformities and is attached through the medium of external artificial elbow joints to the

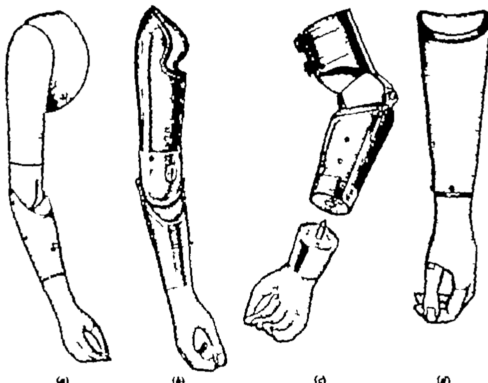


FIG. 401. (*a*) Dress Arm for disarticulation at the shoulder. This arm has forward and outward movement at the shoulder joint and, like the full working arm, has a natural line and appearance. Its weight is reduced to a minimum. An oval wrist can be fitted if the wearer prefers the bisection in the forearm.
(*b*) Heavy and light working arm for an above-elbow amputation. This is a useful and practical working arm with a fully automatic elbow lock which enables the wearer to flex and lock the arm automatically in several positions without using his sound hand. The forearm can be semi-rotated from the elbow on a lateral plane to give greater outward reach or to allow it to rest closer to the body, and the rotary sector enables the hand or appliances to be rotated in either direction and kept there by a locking device.
(*c*) Working arm for a below-elbow amputation—short stump. The moulded inner cup socket of this arm gives maximum comfort and support. The lower section of the forearm can be detached so that working appliances can be brought nearer to the distal end of the stump.
(*d*) Dress arm for a below-elbow amputation. The arm is fitted with Steeplon socket without reinforcing steels. It has a pleasing appearance and hand with articulated fingers.
(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co., London.)

adjustable leather upper arm corset. The artificial joints synchronize with the natural elbow joint but pronation and supination is not possible.

The bisected detachable hand can be plugged into the standarized rotary piece which is able to accept any of the devices described.

(*e*) Through-wrist amputations.

The working arm for a through-wrist amputation is designed to suit the amputation, i.e. the exceptionally long forearm stump, where there is insufficient room to insert a

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It consists of an adjustable leather socket with a metal cuff The socket is adjustable to allow the bulbous end of the stump to pass in easily and so obtain a good fit. The metal cuff is made so as to include a patent rotary wrist sector from which the hand can be detached and any of the many special-purpose appliances plugged in for use.

(*f*) Appliances for partial amputation of the hands and fingers.

Numerous appliances are available for partial amputations of the hand. These take the form of a leather harness laced round the remainder of the hand with an attachment which takes the place of the lost members.

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ARTIFICIAL LIMBS FOR LOWER EXTREMITY

Through-hip Amputation

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There are various types of body suspension for this limb the principal ones being a waistbelt or shoulder brace

Amputation Above the Knee

Light metal or willow legs are suitable, the light metal leg having the advantage of being lighter The limbmaker is also able to fit various forms of frictional knee device which are not possible with the wooden leg.

These legs are made to articulate at the knee and at the ankle by means of ball bearing joints, and suspension where the stump is of adequate length is usually by a double swivel pelvic band, which gives complete freedom of movement at the hip joint.

In selected cases this type of amputation can be fitted with a suction or muscle controlled socket which needs no body suspension.

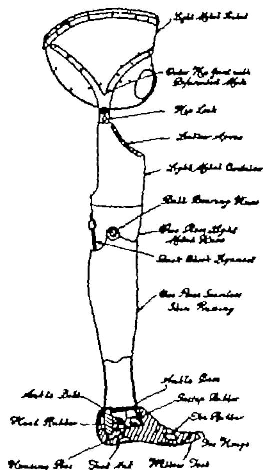


FIG. 402. Diagram showing the construction of a tilting table limb.

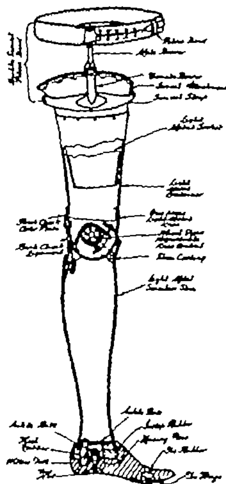


FIG. 403. Diagram showing the construction of an above-knee limb.

(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co., London.)

Amputations Through and Below the Knee

In these types of amputation the stump is usually accommodated in a leather socket moulded to shape, and the weight of the body is distributed evenly over the whole amputation by means of a leather thigh corset which takes a great deal of the weight off the stump. The stump can be completely relieved of weight-bearing by the application of a blocked leather corset which takes the weight of the body on the tuberosity of the ischium.

This type of limb is fitted with ball-bearing knee joints and an articulated ankle.

Syme's Amputation

The type of limb used for these amputations where full weight bearing can be taken is not strictly an artificial limb, but an appliance, and consists of very strong stainless steels to withstand the considerable leverage imposed by the long stump The steels are set upon an ankle base with an articulated ankle and a wood foot.

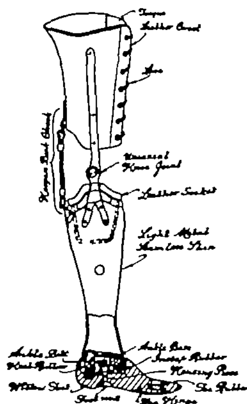


FIG. 404 Diagram showing the construction of below-knee limb.

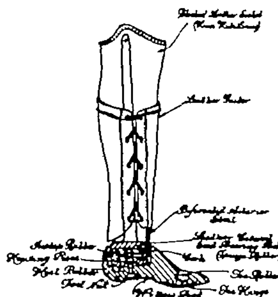


FIG. 405 Diagram showing the construction of an artificial limb for a Syme's amputation.

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In selected cases this type of amputation can be fitted with a suction or muscle controlled socket which needs no body suspension.

FIG 402. Diagram showing the construction of a tilting table limb.

FIG 403 Diagram showing the construction of an above-knee limb.

(From "Artificial Limbs" by L. Gillis, Pitman Medical Publishing Co., London.)

Amputations Through and Below the Knee

In these types of amputation the stump is usually accommodated in a leather socket moulded to shape, and the weight of the body is distributed evenly over the whole amputation by means of a leather thigh corset which takes a great deal of the weight off the stump. The stump can be completely relieved of weight-bearing by the application of a blocked leather corset which takes the weight of the body on the tuberosity of the ischium.

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The type of limb used for these amputations where full weight bearing can be taken is not strictly an artificial limb, but an appliance and consists of very strong stainless steels to withstand the considerable leverage imposed by the long stump The steels are set upon an ankle base with an articulated ankle and a wood foot.

FIG. 404. Diagram showing the construction of a below-knee limb

FIG. 405 Diagram showing the construction of an artificial limb for a Syme's amputation.

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